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Review

Toward Business Management 4.0: A Systematic Literature Review, Gap Analysis, and Conceptual Framework

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Abstract

Business management is undergoing a profound transformation driven by the rapid advancement of technologies associated with Industry 4.0. Organizations are increasingly required to redesign strategies, structures, and operational processes to achieve agility, resilience, and sustainable competitiveness in dynamic and technology-intensive environments. Business Management 4.0 (BM4.0) reflects this emerging paradigm by integrating advanced digital technologies into core managerial functions and enabling intelligent, data-driven decision-making. This study conducts a systematic literature review of academic publications, industry reports, and documented case studies to examine how Industry 4.0 technologies are reshaping contemporary business management practices. The review synthesizes key technological developments and identifies major implementation challenges, including interoperability limitations, cybersecurity risks, and workforce capability gaps. It also highlights best practices adopted by organizations that have successfully leveraged digital technologies to enhance operational performance and strategic responsiveness. Building on these insights, the study proposes a comprehensive BM4.0 conceptual framework that integrates emerging technologies such as Artificial Intelligence, Internet of Things, Blockchain, robotics, and predictive analytics to support more adaptive and intelligent management systems. The framework encompasses seven interrelated dimensions: technological integration enabling real-time automation and decision-making; operational excellence through data-driven optimization; proactive management of interoperability, cybersecurity, and workforce challenges; development of scalable and resilient digital infrastructures; structured implementation roadmaps supported by stakeholder engagement and workforce readiness; continuous improvement through the define, measure, analyze, improve, control (DMAIC) methodology enhanced by AI and blockchain capabilities; and strategic alignment of organizational objectives with key performance indicators through advanced analytics. Together, these dimensions provide an actionable roadmap for organizations seeking to adopt Industry 4.0 technologies, address implementation barriers, and sustain long-term competitive advantage.

Keywords: business management 4.0; digital transformation; business intelligence; data-driven decision-making; operational excellence; continuous improvement

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1. Introduction

Business management is entering a transformative era as organizations confront rapid technological, economic, and social shifts. The convergence of advanced digital technologies, rising customer expectations, and intensifying global competition is redefining traditional business models and operational practices.

Organizations that fail to integrate emerging technologies risk losing efficiency, agility, and long-term competitiveness. In this context, business management 4.0 (BM4.0) has emerged as a strategic paradigm that integrates technological innovation with organizational strategy, enabling data-driven decision-making, operational resilience, and sustainable value creation (Bagnoli et al., 2018). BM4.0 not only supports efficiency and agility but also fosters innovation and sustainability, making it a critical framework for modern business management.

Business management is undergoing a profound transformation with the adoption of technologies associated with Industry 4.0. Technologies such as artificial intelligence (AI), internet of things (IoT), robotics, blockchain, and cloud computing are reshaping production, operations, and decision-making. These innovations enhance productivity, reduce costs, and enable innovative business models. Manufacturing has traditionally led adoption, supported by initiatives such as Make in India and the National Policy on Electronics.

As digital infrastructure and connectivity expand, integrating Industry 4.0 technologies has become essential for sustaining competitiveness across sectors (Abed & Othman, 2014). Adoption, however, remains uneven. While manufacturing and technology-intensive industries have advanced rapidly, agriculture, textiles, and small-scale services face challenges including limited infrastructure, low technological investment, and shortages of skilled personnel. These disparities emphasize the need for a strategic, systematic approach to implementing Industry 4.0 technologies that enhances operational efficiency, innovation, and responsiveness (Ram & Yasin, 2025; Gomaa, 2025).

Within this evolving context, BM4.0 represents a strategic paradigm linking digital transformation with organizational management. By leveraging AI, IoT, Big Data analytics, and automation, BM4.0 facilitates faster innovation cycles, evidence-based decision-making, and personalized customer experiences, while improving operational efficiency and organizational agility (Zapletalová, 2023). These capabilities enable businesses to respond proactively to market disruptions and evolving customer demands. AI-driven digital transformation supports predictive insights, process optimization, and resource efficiency, helping organizations identify opportunities while mitigating risks. Achieving the full potential of BM4.0 requires strong leadership, strategic governance, and an organizational culture that embraces continuous technological change. Moreover, BM4.0 integrates Environmental, Social, and Governance (ESG) principles into digital strategies, fostering sustainable, resilient, and responsible business operations (Yusriadi et al., 2022; Sergi et al., 2022; Sudirman, 2025).

The adoption of Industry 4.0 technologies profoundly affects business management, enabling organizations to innovate, optimize operations, and achieve sustainable growth. AI, IIoT, and Big Data Analytics drive automation and generate real-time actionable insights. Digital Twins and Machine Learning improve forecasting, predictive maintenance, and asset management, while blockchain and Cyber-Physical Systems enhance transparency, security, and system integration. Cloud Computing, 5G, and Edge Computing provide scalable, real-time connectivity and computational capacity, supporting seamless information flow across organizational networks. Robotics, Autonomous Vehicles, and 3D Printing further improve operational efficiency, flexibility, and the ability to deliver customized products and services. The combined application of these technologies allows organizations to respond rapidly to market dynamics, optimize resources, and align digital strategies with sustainability objectives, positioning digital transformation as central to modern business management.

Despite increasing attention to BM4.0, the literature remains fragmented, often focusing on individual technologies or sector-specific applications. Few studies offer a comprehensive framework that integrates technological, operational, and strategic dimensions to guide organizations toward BM4.0 excellence. This gap limits the ability of managers, policymakers, and researchers to systematically implement digital transformation across organizational functions. To address this limitation, the present study proposes a strategic framework for AI-driven digital transformation and BM4.0 excellence. The framework integrates emerging technologies with sustainable management practices to enhance efficiency, foster innovation, and create long-term organizational value. It emphasizes leadership, strategic alignment, and workforce readiness as critical enablers of successful transformation.

The paper is organized as follows: Section 2 reviews the literature on Industry 4.0 and digital transformation, Section 3 identifies research gaps, Section 4 presents the BM4.0 implementation framework, and Section 5 discusses challenges, opportunities, and directions for future research.

2. Literature Review

BM4.0 represents a transformative evolution in how organizations operate, innovate, and compete within the digital economy. By integrating advanced technologies such as AI, IoT, and Big Data analytics, BM4.0 offers organizations greater efficiency, responsiveness, and global competitiveness (Popkova & Sergi, 2020). However, the path to realizing these benefits is often complex and fragmented. Many organizations, despite strategic intentions and technological investments, struggle to meet their digital transformation goals. Research shows that the challenges are not solely rooted in access to capital or technology but extend to organizational, cultural, and strategic misalignments (Chaudhary et al., 2025; Kohtamäki et al., 2024; Sun & Zhang, 2021). Table 1 summarizes the impact of these technologies on efficiency, decision-making, and operational performance.

Table 1. Key Industry 4.0 technologies and their objectives in business management.

No	Technology	Description	Objectives in Business Management
1	Artificial Intelligence (AI)	Automates processes and enhances decision-making with data.	Optimize operations, improve decisions, and increase efficiency.
2	Industrial Internet of Things (IIoT)	Connects devices for real-time monitoring.	Enhance visibility, efficiency, and predictive maintenance.
3	Digital Twins (DT)	Virtual replicas of assets for simulation and optimization.	Minimize downtime, improve agility, and optimize performance.
4	Machine Learning (ML)	Identifies patterns in data for automated decisions.	Automate predictions and enhance decision-making accuracy.
5	Data Analytics (DA)	Extracts insights from structured and unstructured data.	Improve performance, optimize operations, and inform decisions.
6	Big Data Analytics	Analyzes large datasets for real-time insights.	Enhance forecasting and strategic planning.
7	Cloud Computing	Provides on-demand storage and computing.	Increase scalability, flexibility, and collaboration.
8	Digital Kanban Boards	Visualizes workflows and task progress.	Improve transparency and streamline operations.
9	Robotics and Automation	Autonomous machines for repetitive tasks.	Boost speed, accuracy, and cost efficiency.
10	Autonomous Vehicles	Self-driving systems for logistics and transportation.	Optimize logistics, reduce costs, and enhance efficiency.
11	Blockchain Technology	Decentralized ledger for secure transactions.	Improve transparency, security, and trust in operations.
12	Cyber-Physical Systems (CPS)	Integration of digital and physical systems.	Enable automation, enhance monitoring, and optimize operations.
13	Additive Manufacturing (3D Printing)	Layered production for on-demand items.	Reduce lead times and enable customization.
14	Augmented Reality (AR)	Digital overlays for enhanced interaction.	Improve accuracy, efficiency, and training.
15	Virtual Reality (VR)	Immersive environments for simulation and training.	Enhance planning, risk analysis, and employee training.
16	Cognitive Computing	AI-driven systems simulating human reasoning.	Automate complex problem-solving and decision-making.
17	Smart Sensors	IoT-enabled devices for real-time data collection.	Improve monitoring, asset management, and automation.
18	Radio-frequency Identification (RFID)	Wireless tracking of assets and inventory.	Enhance tracking, inventory management, and resource allocation.
19	Edge Computing	Local data processing for faster insights.	Reduce latency and improve real-time response.
20	5G Technology	High-speed, low-latency wireless connectivity.	Enable real-time operations and improve automation.

Rincon-Guio et al. (2023) conducted a systematic literature review and bibliometric analysis examining the convergence of Industry 4.0 and project management. The study traces the historical development and adoption challenges of Industry 4.0 technologies while emphasizing their implications for sustainability. Key insights include the evolving responsibilities of project managers, the strategic adaptation of project practices, and the importance of organizational maturity. The authors argue that education, training, and project governance are critical for successful transformation and call for expanded research into implementation dynamics.

Setyadi et al. (2025) analyzed 181 studies (2019–2024) focusing on sustainability in manufacturing. Their review highlights the growing role of AI, digital twins, and blockchain in enabling circular economy practices—

reducing energy consumption by up to 30% and material waste by 20%. The COVID-19 pandemic served as a digital accelerator, particularly among SMEs in emerging markets, exemplified by PT Indocement's 35% reduction in natural gas use and a 12% increase in digital technology adoption. Nevertheless, regulatory, social, and policy dimensions remain underexplored. The study proposes inclusive strategies to increase equitable access to digital tools and align sustainability objectives with local development priorities.

Sudirman (2025) investigates how digital entrepreneurship fosters innovation and competitiveness among Indonesian SMEs. Through case studies, the research shows how technologies like e-commerce, AI, and cloud computing enhance customer engagement, operational adaptability, and productivity. Success factors include digital readiness, platform strategy, and workforce automation. Challenges, however, remain—including cybersecurity concerns, infrastructure gaps, and resistance to change. The study emphasizes the need for collaborative public-private partnerships, government incentives, and digital literacy programs to support sustainable SME transformation.

Collectively, these studies contribute to a deeper understanding of the opportunities and constraints associated with BM4.0. Tables 2 and 3 classify the literature into six categories, each representing a key thematic area in the evolving BM4.0 landscape.

Table 2. Key studies on industry 4.0 and business excellence.

No	Author(s)	Year	Focus	Key Findings
1	Bordeleau et al.	2020	BI&A in Medium Enterprises	Organizational learning, culture essential for BI&A success.
2	Marques et al.	2020	BI for decision-making in organizations	Developed BI platform to improve supply chain data management.
3	Jankalová & Jankal	2020	Business Excellence & Sustainability in TQM	Linked Business Excellence dimensions to TQM and sustainability.
4	Popkova & Sergi	2020	AI & human intellect in social entrepreneurship	Hybrid AI-human model for decision-making support.
5	Vrchota et al.	2020	CSFs in Industry 4.0 Project Management	Leadership, employee involvement, and resources are key.
6	Tavera Romero et al.	2021	Industry 4.0 Technologies & BI	Industry 4.0 enhances innovation and decision-making.
7	Lopes et al.	2021	ABI in healthcare (Hospital 4.0)	ABI systems improve healthcare services and patient outcomes.
8	Fajsi et al.	2022	Project Management Maturity & Business Excellence	Industry 4.0 influences project management maturity and excellence.
9	Sergi et al.	2022	HR's role in Business 4.0	HRM strategies need to adapt to drive Business 4.0 success.
10	Henriquez et al.	2023	Operational Excellence in emerging countries	Model to assess operational excellence, highlighting barriers.
11	Raddi-Mira et al.	2024	Industry 4.0 Project Implementation Framework	Focus on strategic priorities for successful implementation.
12	Rahim et al.	2024	Industry 4.0 maturity & corporate financial performance	Industry 4.0 maturity boosts business processes and financial outcomes.
13	Pravin & Choube	2025	Electrical & Electronics Engineering sector trends	Insights on renewable energy, smart cities, and AI.
14	Ram & Yasin	2025	Industry 4.0 adoption in India	AI and cloud computing key to adoption and workforce training.
15	Ahmad et al.	2020	BI Systems in Textile & Apparel industry	BIS drives sustainability but faces adoption barriers in non-tech-savvy sectors.
16	Gomaa	2025	Lean Six Sigma & Digital Innovations in Smart Manufacturing	Integrates Lean with Industry 4.0 for operational excellence.
17	Gomaa (2025a)	2025	Lean 4.0 in digitally enhanced manufacturing	Reinterprets Lean for agility and real-time optimization.
18	Gomaa (2025b)	2025	LSS 4.0: Lean & Industry 4.0 integration	Aligns LSS with Industry 4.0 for performance and quality.
19	Gomaa (2025c)	2025	Maintenance 4.0: Predictive strategies for asset integrity	Uses predictive maintenance to optimize uptime and reliability.
20	Gomaa (2025d)	2025	SCM 4.0: Agile, resilient supply chains	Combines Lean and digital tech to enhance supply chain resilience.
21	Gomaa (2025e)	2025	Smart Maintenance: Digital Twins & Lean Six Sigma	Combines Digital Twins with LSS for proactive maintenance.
22	Gomaa (2025f)	2025	RCM 4.0: Reliability-Centered Maintenance	Digitally enhanced RCM model for lifecycle performance.

Table 3. Key categories in industry 4.0 and business management research.

No	Category	Description	Key References
1	Business Intelligence & Industry 4.0 Technologies	How BI, AI, Big Data, and IoT improve decision-making and competitiveness.	Bordeleau et al. (2020); Marques et al. (2020); Tavera Romero et al. (2021); Ahmad et al. (2020)
2	Business Excellence & Sustainability	Integration of TQM, Business Excellence, and sustainability for value creation.	Jankalová & Jankal (2020); Henriquez et al. (2023); Fajsi et al. (2022)
3	Human Resources & Organizational Transformation	The evolving role of HRM in digital competencies, workforce agility, and culture.	Sergi et al. (2022); Pravin & Choube (2025)
4	Industry 4.0 Project Implementation	Frameworks and challenges in Industry 4.0 implementation.	Raddi-Mira et al. (2024); Vrchota et al. (2020)
5	Industry 4.0 Adoption & Economic Impact	Adoption patterns, investment strategies, and economic impacts of Industry 4.0.	Rahim et al. (2024); Ram & Yasin (2025)
6	Smart Manufacturing, Maintenance & Supply Chains	Use of LSS, predictive maintenance, Digital Twins, and Industry 4.0 in optimization.	Gomaa (2025a–f)

Business Intelligence & Industry 4.0 Technologies: This category explores how business intelligence and technologies like AI, IoT, and Big Data enhance decision-making, process transparency, and responsiveness. Bordeleau et al. (2020) and Marques et al. (2020) highlight the importance of digital culture and infrastructure, particularly for medium-sized firms. Tavera Romero et al. (2021) and Lopes et al. (2021) show the positive impacts on innovation and sectoral performance, while Ahmad et al. (2020) emphasizes BI's role in driving environmental sustainability in the apparel industry.

Business Excellence & Sustainability: This stream links performance management frameworks—like TQM—to sustainability outcomes. Jankalová and Jankal (2020) conduct a cross-national study of excellence and sustainability metrics. Henriquez et al. (2023) propose a maturity model for emerging economies, and Fajsi et al. (2022) emphasize the role of project management maturity in aligning quality standards with sustainable development.

Human Resources & Organizational Transformation: Human capital is increasingly recognized as a catalyst for digital transformation. Sergi et al. (2022) call for repositioning human resource from administrative support to strategic transformation enablers. Pravin and Choube (2025) explore how technical professionals are adapting to Industry 4.0 tools, underscoring the importance of reskilling and leadership development.

Industry 4.0 Project Implementation: These studies focus on practical implementation frameworks and transformation strategies. Raddi-Mira et al. (2024) offers a structured implementation roadmap, while Vrchota et al. (2020) highlights key success factors such as leadership commitment and flexibility. Tavera Romero et al. (2021) demonstrate how analytics and connectivity can drive agile decision-making.

Industry 4.0 Adoption & Economic Impact: Research in this area investigates macroeconomic and sectoral impacts of digital adoption. Rahim et al. (2024) link digital maturity to improved financial performance via internal process optimization and supply chain efficiency. Ram and Yasin (2025) study adoption trends in India, identifying sector-specific drivers and barriers while advocating for strategic policy interventions.

Smart Manufacturing, Maintenance & Supply Chain Management: This group represents integrated applications of Industry 4.0 in core operations. Gomaa (2025a–f) presents frameworks combining Lean Six Sigma, AI, Digital Twins, and predictive analytics into strategies for Lean 4.0, Maintenance 4.0, and Supply Chain 4.0. These models enable real-time optimization, enhanced asset integrity, and resilient operations across manufacturing ecosystems.

Although the benefits of BM4.0 are well-documented, its implementation is often hindered by organizational inertia, fragmented strategies, and a lack of alignment between technology and workforce capabilities. Success in Business 4.0 requires more than adopting new tools—it demands integrated, organization-wide transformation anchored in leadership, culture, and continuous capability development (Ferdowsian, 2016). While technological advancements are reshaping manufacturing and operations, the broader integration of digital tools into business strategy, innovation, and decision-making remains an evolving challenge. Future research should emphasize practical frameworks, workforce transformation, and holistic models to bridge the gap between digital ambition and execution.

2.1. Research Gap Analysis

This research gap analysis identifies critical areas within the application of Industry 4.0 technologies in business management (BM) that require further exploration. As transformative technologies, such as autonomous vehicles, AI, blockchain, IoT, and predictive analytics, are increasingly integrated into business operations, significant gaps remain in understanding their holistic implementation, optimization, and long-term impact (Bali et al., 2021). Addressing these gaps is vital for developing strategic frameworks that drive efficiency, agility, resilience, and sustainability in modern business management (Choudhary & Nandy, 2024). Table 4 presents a research gap analysis focused on the integration of Industry 4.0 technologies in BM. It categorizes key research areas into seven groups, each addressing current gaps, challenges, and the necessary actions to advance digital transformation in business operations. These areas emphasize the need for holistic frameworks, technology adoption strategies, AI-driven automation, real-time data processing, digital infrastructure, cybersecurity, sustainability, and resilience.

Table 4. Research gap analysis: Industry 4.0 in business management.

No	Category	No	Research Gap	Current Gap	Research Need	Potential Areas
1	Industry 4.0 Integration & Adoption	1	End-to-End Integration of Industry 4.0	Fragmented adoption of digital technologies in BM	Holistic frameworks for seamless Industry 4.0 integration	AI, IoT, Digital Twins, Cyber-Physical Systems
		2	Barriers to Industry 4.0 Adoption	Resistance, lack of digital culture	Best practices for digital transformation and change management	Change Management, Digital Strategy, Workforce Upskilling
		3	Industry-Specific Adoption of Industry 4.0	Generic solutions not tailored to industry needs	Tailored strategies for sector-specific digital transformation	AI, Regulatory Compliance, Industry-Specific Frameworks
2	AI & Automation in BM	4	AI-Driven Autonomous Decision-Making	AI mainly for predictive insights, not autonomous decisions	Real-time, adaptive AI-driven decision-making in BM	AI, Smart BM, Reinforcement Learning, Autonomous Systems
		5	Real-Time Data Processing in BM	IoT data overload, slow decision-making	AI analytics and edge computing for real-time optimization	AI, ML, Edge Computing, Fog Computing
		6	Big Data & ML for Demand Forecasting	Static forecasting models, lack of adaptability	AI-driven dynamic forecasting and demand sensing	ML, Predictive Analytics, Demand Sensing, NLP for Forecasting
3	Digital Infrastructure & Connectivity	7	Digital Twins in BM Optimization	Limited use for predictive and prescriptive analytics	Real-time applications for BM resilience and optimization	AI, Digital Twins, Simulation Modeling, Augmented Analytics
		8	5G & BM Connectivity	Infrastructure gaps, data transmission delays	Impact of 5G on real-time data sharing and automation	5G, IoT, Edge Computing, Network Slicing
4	Blockchain & Cybersecurity in BM	9	Blockchain Scalability in BM	Interoperability, efficiency, transaction speed issues	Scalable blockchain solutions for cross-border applications	Blockchain, Smart Contracts, Decentralized Networks
		10	Privacy in Blockchain-Enabled BM	Data security, GDPR compliance concerns	Privacy-preserving blockchain solutions	Zero-Knowledge Proofs, Homomorphic Encryption
5	Sustainability & Risk Management	11	Sustainability & Circular Economy in BM	Weak integration of Industry 4.0 in sustainability efforts	Digital tools for resource optimization and carbon tracking	IoT, Green BM, Circular Economy Models, Carbon Footprint Analytics
		12	Integrated Risk & Sustainability Analytics	Risk and sustainability considered separately	Unified frameworks combining risk management and sustainability	ESG, Predictive Risk Analytics, AI-Driven Resilience Models
6	BM Resilience & Collaboration	13	BM Resilience in Global Disruptions	Lack of real-time adaptation frameworks	AI-driven resilience frameworks using real-time monitoring	Risk Analytics, Digital Twins, Scenario Planning

No	Category	No	Research Gap	Current Gap	Research Need	Potential Areas
		14	Cross-Industry Collaboration in BM	Limited data-sharing and collaboration across industries	Strategies to enhance collaboration and agility	Collaboration Networks, Open Data Platforms, Multi-Enterprise BM
7	Economic & Long-Term Impact	15	Economic Impact of Industry 4.0 in Emerging Markets	Unclear long-term benefits, high initial costs	Assessing digital transformation impact on emerging market economies	Infrastructure, Economic Growth, Digital Inclusion, Policy Development
		16	Long-Term Impact of Industry 4.0 on BM	Focus on short-term efficiency gains, lack of long-term studies	Longitudinal studies on Industry 4.0 impact on BM evolution	Future-Proofing BM, Smart Logistics, AI-Enabled Strategy

Industry 4.0 Integration & Adoption: This category identifies the fragmented adoption of Industry 4.0 technologies in BM, which limits seamless integration. Research should focus on developing comprehensive frameworks that integrate AI, IoT, Digital Twins, and Cyber-Physical Systems for end-to-end solutions. Overcoming organizational resistance, cultivating a digital culture, and implementing workforce upskilling programs are essential for effective digital transitions.

AI & Automation in BM: While AI is primarily used for predictive insights, its potential for real-time autonomous decision-making is underexplored. Research should investigate AI-driven systems for adaptive, real-time decision-making in BM and explore how edge and fog computing can improve data processing speeds. Additionally, advancing demand forecasting models using machine learning (ML) and AI to enhance market adaptability is a key area of focus.

Digital Infrastructure & Connectivity: A significant research gap exists in the underutilization of Digital Twins for predictive and prescriptive analytics in BM. Future studies should explore real-time applications of Digital Twins to optimize operations and enhance resilience. Furthermore, addressing infrastructure challenges related to 5G technology, IoT, and edge computing is essential to enable seamless business operations.

Blockchain & Cybersecurity in BM: Blockchain technology faces scalability, interoperability, and transaction speed limitations, particularly in cross-border operations. Research should focus on developing scalable blockchain frameworks to ensure efficiency and security for large-scale applications. Additionally, privacy-preserving blockchain solutions that address data security and GDPR compliance—using techniques like zero-knowledge proofs and confidential computing—are critical.

Sustainability & Risk Management: There is a gap in the integration of Industry 4.0 technologies with sustainability efforts, such as resource optimization and waste reduction. Research should focus on how digital tools can support the circular economy, carbon tracking, and sustainability in BM. Furthermore, combining risk management and sustainability analytics into unified frameworks will be vital for businesses to mitigate risks and ensure long-term, sustainable growth.

BM Resilience & Collaboration: Research gaps exist in developing adaptive frameworks for managing global disruptions (e.g., pandemics, geopolitical crises). AI-driven resilience frameworks leveraging real-time data and predictive analytics are needed to help businesses anticipate and respond to crises. Moreover, strategies to foster cross-industry collaboration through open data platforms and digital ecosystems should be explored to enhance agility and interconnectedness across industries.

Economic & Long-Term Impact of Industry 4.0: This category addresses the unclear long-term economic impact of Industry 4.0, particularly in emerging markets. Research should evaluate the benefits of digital transformation on economic productivity, BM performance, and competitiveness over time. Longitudinal studies are needed to better understand the evolving role of Industry 4.0 technologies in shaping the future of BM and ensuring businesses develop adaptive strategies to stay competitive.

The research gap analysis highlights essential areas for future exploration to advance the integration of industry 4.0 technologies in BM. It underscores the need for comprehensive frameworks, overcoming organizational and technological barriers, improving data processing capabilities, fostering collaboration, and addressing sustainability and resilience challenges. These insights provide a foundation for future research aimed at driving the digital transformation of business management.

3. Methodology

This study adopts a systematic literature review approach to examine the integration of Industry 4.0 technologies within business management and to develop a comprehensive BM4.0 framework. The methodology is designed to ensure rigor, transparency, and replicability in the identification, selection, and synthesis of relevant studies. The review focuses on key Industry 4.0 technologies, including AI, IoT, blockchain, robotics, autonomous systems, and predictive analytics, with the aim of identifying emerging trends, challenges, opportunities, and research gaps in contemporary business management practices.

A structured search strategy was employed to retrieve relevant literature from leading academic databases, including Scopus, Web of Science, and Google Scholar. Boolean operators and carefully selected keyword combinations such as "Industry 4.0" AND "business management," "digital transformation" AND "AI," and "blockchain" OR "IoT" OR "predictive analytics" AND "management" were used to ensure comprehensive coverage. The search was limited to peer-reviewed journal articles, industry reports, and case studies published between 2015 and 2025, thereby capturing the most recent and relevant developments in the field.

To ensure the quality and relevance of the selected studies, predefined inclusion and exclusion criteria were applied. Studies were included if they were peer-reviewed articles, reputable industry reports, or documented case studies focusing on Industry 4.0 technologies in business or management contexts and published in English within the specified timeframe. Studies were excluded if they were non-scholarly sources, unrelated to business management applications, duplicates, or incomplete records.

The study selection process followed a PRISMA-aligned four-stage procedure consisting of identification, screening, eligibility, and inclusion. Initially, a large pool of studies was identified through database searches. In the screening stage, duplicate records were removed, and titles and abstracts were reviewed for relevance. Subsequently, full-text articles were assessed during the eligibility stage to ensure alignment with the inclusion criteria. Finally, only high-quality and contextually relevant studies were retained for inclusion in the review. This systematic filtering process ensured methodological rigor and minimized selection bias.

Following the selection process, data were systematically extracted and analyzed using a thematic approach. The extracted data were categorized into key dimensions, including types of Industry 4.0 technologies, their applications in business management, reported benefits and performance outcomes, implementation challenges, and emerging best practices. This thematic synthesis enabled the identification of recurring patterns and critical insights across the literature.

Based on the synthesized findings, a comprehensive BM4.0 conceptual framework was developed. The framework integrates Industry 4.0 technologies across seven strategic dimensions: technological integration, operational excellence, management of implementation challenges, digital infrastructure development, structured implementation strategies, continuous improvement through DMAIC (Define, Measure, Analyze, Improve, Control), and strategic alignment with organizational objectives. The proposed framework provides a practical and structured roadmap for organizations seeking to enhance efficiency, agility, resilience, and sustainable competitiveness, while highlighting the importance of visionary leadership and strategic planning in achieving successful digital transformation.

4. Results

The study focuses on seven key dimensions that collectively define the proposed BM4.0 framework (Table 5). First, the integration of Industry 4.0 technologies emphasizes the use of AI, IoT, blockchain, and robotics to automate business processes and enable real-time, data-driven decision-making. Second, operational excellence is achieved through the application of predictive analytics and automation, which enhance process efficiency, reduce operational costs, and improve organizational agility in dynamic environments.

Third, the framework addresses overcoming implementation challenges, including issues related to system integration, data flow management, cybersecurity risks, and workforce upskilling, all of which are critical for the successful adoption of BM4.0. Fourth, digital infrastructure development highlights the need for scalable and resilient technological systems capable of supporting real-time analytics, seamless connectivity, and advanced automation capabilities. Fifth, the implementation framework provides a structured roadmap for adopting Industry 4.0 technologies, with particular emphasis on stakeholder alignment, strategic planning, and workforce readiness. Sixth, continuous improvement is facilitated through the application of the DMAIC methodology, enhanced by AI and blockchain technologies to optimize processes and sustain performance

improvements over time. Finally, the seventh dimension focuses on key performance indicators (KPIs) and performance metrics, ensuring alignment between organizational objectives and measurable outcomes, while leveraging advanced analytics to improve decision-making and overall business performance.

This framework provides a comprehensive guide for adopting Industry 4.0 technologies, overcoming challenges, and creating an efficient, sustainable, and adaptable business management system. The BM4.0 framework serves as a roadmap for integrating Industry 4.0 technologies, driving operational excellence, and enhancing business agility. By addressing challenges in integration, workforce development, and cybersecurity, businesses can align with strategic goals, ensuring long-term success and sustainability in the digital era.

Table 5. Strategic framework for BM4.0 implementation.

No	Key Dimension	Objective	Strategic Focus
1	Integration of Industry 4.0	Leverage advanced technologies to optimize BM processes	Use AI, IoT, blockchain, and robotics for automation and real-time decision-making, enhancing operational efficiency.
2	Operational Excellence	Transform business operations into intelligent ecosystems	Employ predictive analytics, AI, and automation to boost agility, reduce costs, and improve process visibility.
3	Overcoming Challenges	Address barriers in technology, data, and workforce	Tackle integration issues, data interoperability, cybersecurity risks, and workforce readiness for smooth BM4.0 adoption.
4	Digital Infrastructure	Build resilient infrastructure for BM4.0	Develop scalable infrastructure to support real-time analytics, AI, and automation for adaptive market responses.
5	Implementation Framework	Provide a structured BM4.0 adoption approach	Create a clear roadmap with stakeholder alignment, workforce readiness, and investments for smooth implementation.
6	Continuous Improvement (DMAIC)	Foster a culture of ongoing optimization	Use the DMAIC methodology to drive continuous process improvement through AI, blockchain, and machine learning.
7	KPIs and Performance Metrics	Align goals with measurable metrics	Define objectives (e.g., agility, cost efficiency, sustainability) and integrate AI and blockchain for transparency.

4.1. Integrating Industry 4.0 in Business Management

The integration of Industry 4.0 technologies, such as IoT, AI, blockchain, and robotics, is revolutionizing BM by driving automation, improving efficiency, and enabling data-driven decision-making. These innovations reduce manual processes, minimize errors, and provide real-time insights, allowing organizations to operate more agilely and enhance customer satisfaction. Table 6 categorizes key Industry 4.0 technologies and their roles within BM4.0. The technologies are grouped into six main areas, each contributing to BM4.0's core objectives: innovation, operational efficiency, agility, and competitiveness. By incorporating these advanced tools, businesses can create smarter, more flexible, and sustainable processes.

Intelligent Decision-Making & Data Analytics: Core technologies like AI, Machine Learning (ML), Cognitive Computing, Data Analytics (DA), and Big Data Analytics drive data-based decision-making and business optimization. These tools process vast amounts of data to detect patterns, optimize resources, manage risks, and predict outcomes, enabling businesses to make faster and more accurate decisions, improving resource management and delivering personalized customer experiences.

Real-time Monitoring & Optimization: Technologies such as IIoT, Smart Sensors, Edge Computing, Digital Twins (DT), and Cyber-Physical Systems (CPS) provide real-time data monitoring and continuous operational optimization. IIoT and smart sensors gather data, which is processed by edge computing for quick insights. Digital twins offer virtual simulations of physical systems, while CPS integrates the digital and physical worlds to optimize asset performance and overall operational efficiency.

Automation & Process Efficiency: Robotics & Automation, Autonomous Vehicles, 3D Printing, and Digital Kanban improve business efficiency by automating routine tasks and streamlining operations. Robotics and autonomous vehicles enhance flexibility in manufacturing and logistics, while 3D printing supports customized, on-demand production. Digital Kanban visualizes workflows, optimizing production schedules and reducing waste, leading to cost savings and quicker response times to market changes.

Table 6. Classification of key industry 4.0 technologies in BM4.0.

No	Category	Technology	Role in BM4.0
1	Intelligent Decision-Making & Data Analytics	AI, ML, Cognitive Computing, Data Analytics, Big Data Analytics	Automates decision-making and pattern recognition, enabling predictive analytics for improved resource management, risk mitigation, and customer experience.
2	Real-time Monitoring & Optimization	IIoT, Smart Sensors, Edge Computing, Digital Twins (DT), CPS	Integrates digital and physical systems for continuous monitoring and real-time optimization, enhancing operational efficiency and asset performance.
3	Automation & Process Efficiency	Robotics & Automation, Autonomous Vehicles, 3D Printing, Digital Kanban	Automates operations and streamlines processes, boosting production efficiency, logistics, and lean manufacturing through intelligent systems and flexible production.
4	Connectivity & Communication	5G Technology, Blockchain, Cloud Computing	Provides high-speed connectivity, secure decentralized transactions, and scalable cloud infrastructure to enable seamless integration and operational agility.
5	Immersive Technologies for Training & Design	Augmented Reality (AR), Virtual Reality (VR)	Supports training, design, and customer engagement through immersive, real-world simulations, accelerating innovation and market responsiveness.
6	Business Operations & Asset Management	RFID Technology, Blockchain	Enhances asset tracking, inventory management, and supply chain transparency with secure, real-time data exchange for reliable and efficient business operations.

Connectivity & Communication: 5G, Blockchain, and Cloud Computing form the foundation of modern business connectivity and secure data exchange. 5G enables fast, low-latency communication essential for real-time applications. Blockchain ensures secure, transparent, and decentralized transactions, particularly in supply chain management. Cloud Computing offers scalable infrastructure for data storage, processing, and collaboration, enabling agile and global business operations.

Immersive Technologies for Training & Design: Augmented Reality (AR) and Virtual Reality (VR) are transformative for training, design, and customer engagement. AR overlays digital data onto the physical world, supporting decision-making and enabling remote collaboration. It is especially effective in training scenarios requiring hands-on experience. VR creates immersive simulations for training and product design, allowing businesses to test concepts without the expense and risks of physical prototypes.

Business Operations & Asset Management: RFID and Blockchain optimize asset management and business operations. RFID enables real-time tracking of assets and inventory, improving efficiency and reducing losses. Blockchain enhances transaction security and transparency, particularly for supply chain traceability and asset management. These technologies help streamline operations, reduce inefficiencies, and ensure data integrity across business processes.

These six categories represent the core pillars of BM4.0. By adopting Industry 4.0 technologies, organizations can enhance decision-making, automate processes, and improve operational efficiency while strengthening connectivity and adaptability. The integration of these technologies ensures businesses remain agile, competitive, and resilient in an increasingly digital world, fostering continuous innovation and long-term success.

4.2. Achieving Operational Excellence

Operational excellence is increasingly driven by advanced technologies like automation, predictive analytics, and AI-powered intelligence. Table 7 outlines key technologies in the BM4.0 framework, categorized by their functions and applications, which enhance efficiency and enable data-driven decision-making.

Automation & Operational Efficiency: Robotics, AI-driven inventory management, and autonomous logistics improve efficiency by reducing manual tasks, speeding processes, and minimizing errors, allowing businesses to adapt quickly to market demands and reduce costs.

Predictive Analytics & Data-Driven Decision-Making: AI, cognitive computing, and predictive analytics automate decision-making and trend forecasting, processing large datasets to optimize resource allocation, manage risks, and improve business strategies proactively.

Real-Time Monitoring & Process Optimization: IIoT, smart sensors, and digital twins enable real-time monitoring and process optimization. These technologies integrate physical and digital systems, offering immediate insights and enabling continuous improvements in performance.

Table 7. Summary of BM4.0 technologies and their applications.

No	Category	Technology	Key Applications
1	Automation & Efficiency	Robotics, Automation	AI-driven inventory management, robotic warehousing, autonomous logistics
2	Predictive Analytics & Decision-Making	Predictive Analytics, AI, Cognitive Computing	Demand forecasting, risk analysis, route optimization, AI-driven decision-making
3	Real-time Monitoring & Optimization	IIoT, Digital Twins, Cyber-Physical Systems, Edge Computing	Asset tracking, fleet management, smart warehousing, real-time process optimization
4	Connectivity & Communication	Blockchain, Cloud Computing, 5G	Secure transactions, product traceability, cloud ERP, real-time shipment tracking, decentralized data exchange
5	Production Flexibility & Innovation	3D Printing (Additive Manufacturing)	Rapid prototyping, spare parts production, on-demand and localized production
6	Immersive Technologies	Augmented Reality (AR), Virtual Reality (VR)	AR-guided picking, VR-based workforce training, immersive product design and simulation
7	Quality Control & Monitoring	Smart Sensors, RFID	Real-time condition monitoring (e.g., cold chain, warehouse sensing), automated inventory tracking
8	Lean Operations & Inventory Management	Digital Kanban	Just-in-Time (JIT) inventory, workflow optimization, lean manufacturing
9	Security & Transparency	Blockchain, RFID Technology	Secure transactions, product traceability, supply chain transparency, real-time asset tracking
10	Business Intelligence & Data Analytics	Big Data Analytics, Data Analytics (DA)	Market insights, fraud detection, supplier performance tracking, customer behavior analysis
11	Agility & Flexibility in Operations	Robotics, Autonomous Vehicles, 3D Printing	Adaptive production lines, autonomous transport systems, flexible manufacturing processes
12	Collaboration & Integration	Cloud Computing, Blockchain	Cloud ERP, supplier collaboration, decentralized data exchange, distributed inventory management

Connectivity & Secure Communication: Blockchain, 5G, and cloud computing ensure seamless communication, secure transactions, and scalable infrastructure, supporting efficient, real-time data exchange across business operations.

Flexible Production & Innovation: 3D printing enables rapid prototyping and on-demand production, allowing businesses to reduce lead times and create customized products while adapting quickly to market needs.

Immersive Training & Simulation: AR and VR enhance training, product design, and customer engagement by providing immersive experiences that accelerate innovation and improve operational readiness.

Quality Control & Real-Time Monitoring: Smart sensors and RFID technology enable precise, real-time monitoring of assets, improving quality control and reducing errors across the supply chain.

Lean Operations & Inventory Management: Digital Kanban supports lean manufacturing by optimizing workflows and inventory levels, reducing waste, and ensuring timely resource availability without overstocking.

Security, Transparency, & Trust: Blockchain and RFID enhance security, transparency, and traceability across business operations, ensuring secure transactions and real-time tracking of assets, reducing fraud.

Big Data & Business Intelligence: Big Data Analytics transforms data into actionable insights, improving decision-making, enhancing supplier performance tracking, and supporting fraud detection.

Agility & Production Flexibility: Robotics, autonomous vehicles, and 3D printing increase agility, enabling rapid production adjustments and more responsive supply chains.

Collaboration & Integration: Cloud computing and blockchain support collaboration and integration, providing scalable storage and secure, transparent transactions across business operations.

These technologies drive the success of BM4.0 by improving business operations, enhancing decision-making, and fostering innovation. By integrating them, businesses can stay competitive, optimize processes, and deliver superior customer experiences.

4.3. Challenges to Achieving Operational Excellence in BM 4.0

Achieving operational excellence through technologies like automation, predictive analytics, and AI presents several challenges. Table 8 highlights the key obstacles businesses face in integrating and scaling these technologies within the BM4.0 framework. These challenges are grouped into eight key categories:

Data Management & Decision-Making: Poor data integration and quality lead to delays and poor decision-making. Adopting cloud platforms, APIs, IoT, Big Data, and AI helps integrate data, improve decision-making, and enable data-driven strategies.

Security & Risk Management: Cybersecurity risks and regulatory compliance requirements are significant concerns. Blockchain, AI, IoT, and Cloud Computing provide secure data protection and ensure compliance with regulations.

System Performance & Scalability: As businesses grow, inefficiencies and bottlenecks can emerge. Cloud computing, IoT, AI, and Edge Computing offer flexibility, enabling real-time performance monitoring and efficient scaling.

Organizational Adaptability: Resistance to change and skill gaps can hinder technology adoption. AI, Automation, Cloud Computing, and Edge Computing streamline workflows, support seamless transitions, and promote a culture of continuous learning.

Operations Efficiency & Transparency: Lack of transparency can lead to inefficiencies. Technologies like IoT, RFID, and Blockchain provide real-time monitoring and transparent tracking, improving efficiency, decision-making, and resource allocation.

Customer Experience & Forecasting: Meeting customer expectations and forecasting demand are increasingly complex. AI, Predictive Analytics, IoT, and Automation enhance demand forecasting, automate processes, and improve responsiveness.

Financial & Resource Management: High technology implementation costs and sustainability concerns pose challenges. AI, Predictive Analytics, IoT, and Green Tech optimize resources, reduce waste, and help businesses meet environmental goals while remaining profitable.

Sustainability & Environmental Impact: Companies must address sustainability concerns. AI, Blockchain, IoT, and Green Tech help track resources, reduce energy consumption, and monitor environmental factors, facilitating more efficient sustainability efforts.

Table 8. Challenges to achieving operational excellence in BM4.0.

No	Group	Challenges	Key Technologies Involved
1	Data Management & Decision-Making	1.1 Data Integration 1.2 Data Quality and Accuracy 1.3 Business Operations Visibility 1.4 Business Operations Complexity	Cloud, APIs, IoT, Big Data, AI, Blockchain, Predictive Analytics
2	Security & Risk Management	2.1 Cybersecurity Risks 2.2 Regulatory Compliance	Blockchain, AI, IoT, Cloud
3	System Performance & Scalability	3.1 Scalability 3.2 Technology Implementation Costs	Cloud, IoT, AI, Edge Computing
4	Organizational Adaptability	4.1 Change Management 4.2 Skill Gaps and Workforce Shortages	AI, Automation, Cloud, Edge Computing
5	Operations Efficiency & Transparency	5.1 Business Operations Visibility 5.2 Interoperability of Technologies	IoT, RFID, Blockchain, Cloud, APIs
6	Customer Experience & Forecasting	6.1 Customer Expectations	AI, Predictive Analytics, IoT, Automation
7	Financial & Resource Management	7.1 Business Operations Disruptions 7.2 Environmental Sustainability 7.3 Technology Implementation Costs	AI, Predictive Analytics, IoT, Blockchain, Green Tech
8	Sustainability & Environmental Impact	8.1 Environmental Sustainability	AI, Blockchain, IoT, Green Tech

Operational excellence requires overcoming challenges in data management, security, scalability, adaptability, and sustainability. By leveraging AI, IoT, Blockchain, and Cloud Computing, businesses can streamline operations, improve transparency, enhance security, and ensure compliance. These technologies form the backbone of efficient, resilient, and sustainable operations that can adapt to an evolving business environment, providing a competitive edge.

4.4. Key Components for BM4.0 Digital Infrastructure

The success of BM4.0 relies on integrating advanced digital technologies to improve operational efficiency, decision-making, and customer satisfaction. Table 9 outlines the essential components of a BM4.0 digital infrastructure, detailing the key objectives and technologies that enable businesses to thrive in the digital era.

Table 9. Key components for BM4.0 digital infrastructure.

No	Category	Objective	Key Components
1	Data Management & Analytics	Enable data-driven strategies and forecasting	1) Centralized real-time data for decision-making. 2) AI-driven demand forecasting. 3) Machine Learning for actionable insights. 4) AI-powered business optimization. 5) Intelligent inventory management.
2	Cloud & Connectivity	Enhance scalability, flexibility, and agility	1) Scalable cloud storage and sharing. 2) Edge computing for low latency. 3) 5G connectivity for fast data exchange. 4) Mobile-first infrastructure for global access.
3	Automation & AI Integration	Drive operational efficiency and adaptability	1) AI and automation for optimized workflows. 2) Robotic Process Automation (RPA) for efficiency. 3) Autonomous systems for logistics and delivery.
4	Cybersecurity & Compliance	Safeguard data integrity and ensure regulatory compliance	1) Multi-layered cybersecurity. 2) Blockchain for secure transactions. 3) Compliance tools for data privacy laws.
5	Business Operations Transparency & Security	Strengthen trust and security in operations	1) Blockchain for transparent transactions. 2) Enhanced cryptography for data security. 3) Smart contracts for process automation.
6	Predictive Maintenance & Asset Management	Maximize asset efficiency and reduce downtime	1) Predictive maintenance with AI and IoT. 2) Digital Twin technology for asset monitoring. 3) Predictive asset lifecycle models.
7	Sustainability & Environmental Impact	Reduce environmental footprint and ensure sustainability	1) Sustainability monitoring with AI. 2) IoT-enabled waste tracking. 3) AI for carbon footprint reduction.
8	Business Operations Optimization & Efficiency	Enhance performance and operational agility	1) Real-time business visibility. 2) Digital control towers for decision-making. 3) Dynamic, AI-driven supply chain collaboration. 4) Adaptive logistics for agile response.
9	Collaboration & Workforce Optimization	Improve workforce productivity and coordination	1) AI-driven collaboration tools. 2) Cobots for enhanced efficiency. 3) Workforce management powered by AI.
10	Customer Experience & Innovation	Enhance customer engagement and foster product innovation	1) AI-powered customer support (chatbots, assistants). 2) Agile product development tools. 3) Real-time customer insights for personalization.

Data Management and Analytics: Data-driven decision-making and forecasting are crucial for operational excellence. Centralized, real-time data, powered by AI and advanced analytics, allows businesses to optimize demand, improve forecasting, and reduce waste. These technologies enable proactive decision-making, enhance supply chain performance, and ensure more efficient inventory management.

Cloud and Connectivity: Cloud solutions provide scalability, flexibility, and mobility, while edge computing reduces latency for faster decision-making. 5G connectivity accelerates data exchange across operations. A mobile-first approach ensures real-time access to critical data, enhancing agility and responsiveness for managers on the go.

Automation and AI Integration: Automation and AI improve operational efficiency and adaptability by reducing manual tasks and optimizing workflows. Robotic Process Automation (RPA) streamlines repetitive processes, while autonomous systems (e.g., drones) enhance logistics and delivery efficiency, ensuring smoother operations across the business.

Cybersecurity and Compliance: Robust cybersecurity measures protect sensitive data, while compliance with privacy regulations (e.g., GDPR) is essential. AI-powered threat detection and blockchain technology ensure data integrity, secure transactions, and compliance, mitigating risks and enhancing business security.

Business Operations Transparency and Security: Blockchain enables transparent transactions and traceable business operations, while smart contracts automate compliance and processes. These technologies build trust,

improve security, and ensure operational integrity, crucial for fostering strong partnerships and managing complex supply networks.

Predictive Maintenance and Asset Management: AI and IoT-powered predictive maintenance reduce downtime and extend asset lifecycles. Digital twins simulate and monitor assets, optimizing performance and enabling proactive maintenance. This approach helps businesses avoid costly breakdowns and optimize asset usage over time.

Sustainability and Environmental Impact: AI, IoT, and green technologies play a key role in reducing environmental impact. Real-time sustainability monitoring allows businesses to optimize energy use, reduce waste, and comply with environmental regulations, supporting sustainability goals and enhancing corporate responsibility.

Business Operations Optimization and Efficiency: Digital control towers and AI-driven systems provide real-time visibility into operations, enabling dynamic adjustments. Integrated supplier networks and adaptive logistics ensure efficient operations and quick responses to changing market conditions, improving overall business performance.

Collaboration and Workforce Optimization: Centralized collaboration platforms enhance team coordination, while human-robot collaboration (cobots) boosts productivity and safety. AI-powered workforce management ensures optimal resource allocation, reducing operational bottlenecks and increasing workforce efficiency.

Customer Experience and Innovation: AI-driven customer support (chatbots, voice assistants) provides 24/7 assistance, improving satisfaction. Digital collaboration tools enable agile product development, allowing businesses to innovate faster. Real-time customer insights facilitate personalized services, enhancing customer engagement and loyalty.

By integrating these technologies into a cohesive digital infrastructure, businesses can build supply chains that are more efficient, resilient, and adaptable. These advancements not only optimize operational processes but also enhance overall supply chain visibility, flexibility, and sustainability, positioning organizations to thrive in an ever-changing business landscape.

4.5. Strategic Implementation Framework for BM4.0

The transition to BM4.0 requires a structured approach that integrates advanced technologies, optimized processes, and organizational transformation. A clear implementation roadmap is essential, focusing on planning, stakeholder engagement, workforce readiness, and digital infrastructure to ensure a smooth transition. The Integrated Strategic Roadmap for BM4.0 outlines a phased approach—Short-Term (0–12 months), Mid-Term (12–36 months), and Long-Term (36–60+ months)—guiding businesses from initial adoption to full digital maturity. This framework leverages technologies such as AI, blockchain, and IoT to drive customer-centric strategies, operational agility, and sustainability, while building the necessary infrastructure, culture, and capabilities for success. Table 10 highlights the key focus areas and actions necessary for effective BM4.0 implementation, ensuring the seamless integration of cultural, technological, and collaborative elements. The implementation of BM4.0 can be conceptualized as a three-phase evolutionary process consisting of short-term foundation building, mid-term acceleration and expansion, and long-term maturity and innovation leadership. Each phase reflects increasing levels of technological integration, organizational capability, and strategic alignment.

In the short-term phase (0–12 months), organizations focus on foundation building to support digital transformation. This begins with strengthening change leadership and organizational mindset through initiatives such as digital leadership academies and the development of change champions to prepare leaders for transformation. Simultaneously, organizations develop a customer-centric digital strategy by implementing AI-powered analytics to enhance decision-making based on customer feedback. Early adoption of AI-enabled intelligent operations is initiated through pilot projects in predictive analytics and automation to improve operational efficiency. Organizations also emphasize extended ecosystem collaboration by forming partnerships with technology vendors and startups. In addition, integrated monitoring and performance intelligence systems are established through dashboards and basic data collection practices to track key metrics. Finally, organizations develop a preliminary business continuity architecture by conducting risk assessments and designing initial continuity plans.

Table 10. Integrated strategic roadmap for BM4.0 implementation.

Phase	No	Strategic Element	Key Actions
A. Short-Term (0–12 months) — Foundation Building	1	Change Leadership & Organizational Mindset	Launch digital leadership academies; train change champions
	2	Customer-Centric Digital Strategy	Implement AI-powered customer analytics; collect and analyze feedback
		AI-Enabled Intelligent Operations	Pilot AI projects (predictive analytics, automation); initiate AI awareness programs
	3	Extended Ecosystem Collaboration	Establish partnerships with technology vendors and startups; formalize collaboration agreements
	4	Integrated Monitoring & Performance Intelligence	Implement operational dashboards; standardize data collection
	5	Business Continuity Architecture	Conduct risk assessments; develop business continuity plans
B. Mid-Term (12–36 months) — Acceleration & Expansion	1	Change Leadership & Organizational Mindset	Embed digital KPIs; foster agile experimentation culture
	2	Customer-Centric Digital Strategy	Scale hyper-personalization initiatives; create co-creation platforms
	3	AI-Enabled Intelligent Operations	Expand AI across departments; strengthen AI Centers of Excellence
	4	Extended Ecosystem Collaboration	Implement blockchain-enabled platforms; formalize innovation hubs
	5	Integrated Monitoring & Performance Intelligence	Deploy predictive analytics; enhance real-time monitoring
	6	Agility Across Business Operations	Scale agile frameworks; use digital twins for simulations
	7	Sustainability-Embedded Business Models	Pilot IoT-enabled sustainability tracking; launch circular products
C. Long-Term (36–60+ months) — Innovation Leadership & Full Maturity	1	Change Leadership & Organizational Mindset	Institutionalize continuous innovation; achieve leadership digital maturity
	2	Customer-Centric Digital Strategy	Implement predictive service models; integrate customer feedback into development
	3	AI-Enabled Intelligent Operations	Move to autonomous decision-making; govern AI adaptively enterprise-wide
	4	Extended Ecosystem Collaboration	Lead global innovation ecosystems; monetize shared platforms
	5	Integrated Monitoring & Performance Intelligence	Transition to self-correcting systems; automate performance management
	6	Agility Across Business Operations	Achieve hyper-agility; autonomously respond to market shifts
	7	Sustainability-Embedded Business Models	Achieve net-zero operations; commercialize sustainability as a core business strategy
	8	Business Continuity Architecture	Maintain predictive risk models; simulate disruptions and ensure adaptability

In the mid-term phase (12–36 months), organizations move toward acceleration and expansion by scaling successful initiatives and integrating more advanced technologies. During this stage, change leadership is reinforced by embedding digital key performance indicators (KPIs) and fostering a culture of agile experimentation. The customer-centric strategy evolves toward hyper-personalization and the development of customer co-creation platforms. AI-enabled operations are expanded across the organization, often supported by the establishment of centers of excellence to drive innovation. Organizations enhance ecosystem collaboration through the implementation of blockchain-enabled platforms that improve transparency and efficiency with external partners. Furthermore, integrated monitoring systems are upgraded with predictive analytics and real-time tracking capabilities. Greater agility across business operations is achieved through the adoption of agile frameworks and the use of digital twins for simulation and optimization. At the same time, organizations begin embedding sustainability into their models by introducing IoT systems for tracking environmental performance and piloting circular product initiatives.

In the long-term phase (36–60+ months), organizations reach full maturity and innovation leadership, characterized by advanced digital integration and strategic transformation. Change leadership becomes

institutionalized, with continuous innovation embedded into the organizational culture and leadership achieving full digital maturity. The customer-centric strategy advances to predictive service models, where customer feedback is seamlessly integrated into product and service development. AI-enabled operations evolve toward autonomous decision-making supported by adaptive AI governance frameworks. Organizations take a leading role in extended ecosystem collaboration, participating in global innovation networks and leveraging digital platforms to create new revenue streams. Integrated monitoring and performance intelligence systems become self-correcting, enabling automated and intelligent performance management. High levels of organizational agility allow firms to respond autonomously and in real time to market changes. Additionally, sustainability becomes a core strategic priority, with organizations striving for net-zero operations. Finally, advanced business continuity architectures are established, incorporating predictive risk modeling and simulation capabilities to ensure rapid adaptation and resilience in dynamic environments.

This roadmap provides a clear, actionable framework for organizations to execute their BM4.0 strategies. By integrating cutting-edge technologies, fostering organizational agility, and enhancing collaboration, businesses can build operations that are not only efficient and resilient but also adaptable to future challenges. Prioritizing change management, customer-centric strategies, AI integration, and sustainability will enable organizations to thrive in an increasingly competitive and dynamic market.

4.6. Application of DMAIC for Continuous Improvement in BM4.0

The DMAIC (Define, Measure, Analyze, Improve, Control) methodology is central to achieving continuous improvement and operational excellence in BM4.0. By integrating technologies like AI, machine learning, digital twins, and blockchain, organizations can enhance decision-making, reduce risks, and optimize supply chain efficiency. DMAIC helps identify inefficiencies and drive ongoing improvements in performance, resilience, and adaptability. Table 11 summarizes the application of each DMAIC phase in BM4.0.

Table 11. DMAIC framework for BM4.0 implementation.

No	Phases	Objective	Key Activities	Tools	Outcomes
1	Define	Align BM4.0 goals with business objectives.	1) Conduct stakeholder analysis. 2) Set SMART goals. 3) Define KPIs.	Stakeholder mapping, KPI frameworks	Clear, measurable goals aligned with business strategy.
2	Measure	Evaluate current performance and identify gaps.	1) Collect performance data. 2) Benchmark operations.	IoT, Cloud platforms, Data visualization	Performance baseline, identified gaps and inefficiencies.
3	Analyze	Identify causes of inefficiencies and gaps.	1) Analyze data for inefficiencies. 2) Apply AI/ML for insights.	AI/ML, Predictive analytics	Root causes identified, actionable insights generated.
4	Improve	Optimize processes and test improvements.	1) Implement process improvements. 2) Use AI, digital twins, and RPA for optimization.	Digital twins, AI/ML, RPA	Process improvements implemented, optimized workflows.
5	Control	Ensure sustained improvements.	1) Set up monitoring systems. 2) Provide employee training.	Real-time monitoring, Dashboards	Continuous monitoring, sustained performance improvements.
6	Continuous Improvement	Foster a culture of innovation and adaptability.	1) Implement feedback loops. 2) Promote collaboration and knowledge sharing.	Feedback systems, LMS, Collaboration tools	Ongoing innovation, continuous process optimization.

Define Phase: Align BM4.0 goals with business strategy by conducting stakeholder analysis and setting SMART goals. KPIs are established to track progress. The outcome is clear, measurable objectives aligned with the organization's long-term vision.

Measure Phase: Assess current performance using data collection and benchmarking. Technologies like IoT sensors and cloud analytics provide real-time insights, establishing a performance baseline. The outcome is the identification of performance gaps, providing a foundation for improvement.

Analyze Phase: Identify root causes of inefficiencies using AI/ML and predictive analytics. By analyzing data patterns, organizations can target areas for improvement. The outcome is a clear understanding of inefficiencies, enabling focused optimization efforts.

Improve Phase: Optimize processes through pilot projects and real-time implementations using digital twins, AI, and RPA. These technologies ensure scalable, adaptable improvements. The outcome is enhanced efficiency and quality across operations.

Control Phase: Sustain improvements through real-time monitoring, dynamic dashboards, and employee training. This phase ensures long-term stability and performance consistency. The outcome is ongoing optimization supported by a culture of continuous improvement.

Continuous Improvement Phase: Foster innovation and adaptability by using feedback systems and encouraging cross-functional collaboration. Technologies like LMS and collaboration tools support continuous learning. The outcome is a resilient organization that continuously drives innovation and improvement.

DMAIC offers a systematic framework for continuous improvement in SCM 4.0, leveraging AI, blockchain, and digital twins to enhance decision-making and performance. By integrating these technologies, organizations can address inefficiencies, implement effective solutions, and build a sustainable, customer-centric supply chain.

4.7. Establishing Strategic Objectives and Performance Metrics for BM4.0

Strategic objectives like agility, cost efficiency, and sustainability are pivotal for success in BM4.0. These objectives are supported by advanced KPIs, including AI-driven demand forecasting, blockchain transparency, and predictive analytics for disruption management. A robust, data-driven performance measurement system enables agile decision-making and efficient resource allocation in increasingly complex supply chains. However, aligning KPIs with evolving business goals requires ongoing refinement. Table 12 provides a framework for achieving BM4.0 excellence by aligning strategic objectives with measurable KPIs across key business areas.

Table 12. Strategic objectives and KPIs for achieving BM4.0 excellence.

No	Area	Strategic Objective	KPIs
1	Operational Efficiency	Optimize operations and reduce waste	OEE (Overall Equipment Efficiency), Cycle time reduction, Resource utilization, Downtime reduction, Cost per unit
2	Cost Management	Drive cost-effectiveness while ensuring compliance	Cost per unit, Lean savings, Regulatory compliance rate, Audit success rate
3	Agility and Flexibility	Enhance responsiveness and adaptability	Lead time reduction, On-time delivery performance, Production schedule adaptability
4	Sustainability	Implement sustainable practices and ethical sourcing	Carbon footprint reduction, Renewable energy use, Waste recycling rate, Sustainability certification compliance
5	Customer Focus	Improve customer satisfaction and collaboration	Customer satisfaction (CSAT), Net Promoter Score (NPS), Customer retention rate, On-time delivery, Order accuracy
6	Innovation and Technology	Drive digital transformation and innovation	R&D investment as % of revenue, Time-to-market for new products, Adoption of AI/ML, Productivity improvements
7	Digital Integration	Integrate digital tools for operational excellence	ERP system utilization, IoT integration, Automation rate, Big data adoption
8	Data-Driven Decision Making	Empower decisions with analytics and AI	Predictive analytics accuracy, Data quality score, Real-time decision-making effectiveness, AI model performance
9	Risk Management	Enhance risk resilience and management	Risk mitigation effectiveness, Supply chain resilience index, Disruption recovery time
10	Talent and Leadership	Strengthen leadership and workforce development	Employee engagement score, Leadership training participation, Talent retention rate, Diversity and inclusion

Operational Efficiency: The focus is on optimizing internal processes to reduce waste and improve productivity. KPIs like OEE (Overall Equipment Efficiency) and cycle time reduction track how efficiently resources are utilized, helping to improve operational performance at reduced costs.

Cost Management: This objective seeks cost-effectiveness while ensuring regulatory compliance. KPIs such as cost per unit, lean savings, and regulatory compliance track resource utilization and adherence to legal and environmental standards, reducing risks associated with non-compliance.

Agility and Flexibility: The goal is to enhance responsiveness to market changes and operational challenges. KPIs like lead time reduction and on-time delivery measure adaptability and timely service delivery, ensuring customer satisfaction and competitiveness.

Sustainability: This area emphasizes environmentally friendly and ethical business practices. KPIs such as carbon footprint reduction and renewable energy use help track progress in sustainability efforts, which are crucial for regulatory compliance and brand reputation.

Customer Focus: The objective is to improve the customer experience continuously. KPIs like customer satisfaction (CSAT) and Net Promoter Score (NPS) measure how well the company meets customer expectations and loyalty, critical for building long-term relationships.

Innovation and Technology: The focus here is on leveraging digital transformation to stay competitive. KPIs such as R&D investment and time-to-market for new products track the company's ability to innovate and introduce solutions quickly, ensuring continued market leadership.

Digital Integration: Digital tools and technologies are integrated to optimize operations. KPIs like ERP system utilization and IoT integration help monitor the deployment of digital solutions that enhance operational efficiency, automation, and real-time decision-making.

Data-Driven Decision Making: This objective focuses on leveraging advanced analytics for informed decision-making. KPIs such as predictive analytics accuracy and real-time decision-making effectiveness track the company's ability to make data-driven, strategic decisions.

Risk Management: The goal is to improve resilience and risk mitigation capabilities. KPIs like risk mitigation effectiveness and disruption recovery time measure how effectively the company manages risks, ensuring long-term operational continuity and minimizing disruptions.

Talent and Leadership: This area focuses on strengthening leadership capabilities and workforce development. KPIs like employee engagement and leadership training participation track the effectiveness of talent development programs, fostering a culture of continuous learning and innovation.

Aligning strategic objectives with KPIs is crucial for BM4.0 success, driving optimization in efficiency, sustainability, and agility. By leveraging technologies like AI, IoT, blockchain, and predictive analytics, businesses can improve decision-making and manage risks effectively. A dynamic strategic framework allows companies to adapt to market shifts and technological advancements, fostering continuous innovation. Through data-driven insights, organizations can ensure long-term growth, resilience, and a competitive edge in the evolving digital landscape.

5. Future Research Directions

Future research should focus on empirically validating the proposed BM4.0 framework through diverse methodological approaches, including longitudinal case studies, large-scale surveys, and pilot implementations across different industries. Such empirical investigations would enhance the robustness, generalizability, and practical applicability of the framework.

Further studies are encouraged to explore industry-specific adaptations of BM4.0, particularly in sectors such as healthcare, supply chain management, finance, and manufacturing, where technological integration presents unique challenges and opportunities. In addition, deeper investigation into the human–technology interface is essential, particularly in areas such as workforce reskilling, change management, organizational culture, and ethical governance of advanced technologies.

Another promising direction involves the development of BM4.0 digital maturity models, which can support organizations in assessing their readiness, benchmarking performance, and guiding staged transformation efforts. Future research may also examine the role of governance frameworks and regulatory environments in facilitating or constraining digital transformation initiatives.

Finally, as technological innovation continues to evolve, future studies should extend the scope of BM4.0 by incorporating emerging paradigms beyond Industry 4.0, including developments associated with Industry 5.0 and Industry 6.0. The integration of advanced technologies such as quantum computing, emotional AI, and human-centric intelligent systems presents significant opportunities to further enhance the adaptability, sustainability, and strategic value of the BM4.0 framework.

6. Conclusion

This study demonstrates that the rapid evolution of Industry 4.0 technologies is fundamentally transforming business management, requiring organizations to reconfigure their strategies, processes, and structures to achieve greater agility, resilience, and sustainable competitiveness. The concept of BM4.0 reflects

this paradigm shift by embedding advanced digital technologies into core business functions and redefining how organizations innovate, adapt, and deliver value in increasingly dynamic and technology-driven environments. Through a systematic review of academic literature, industry reports, and case studies, the study identified key emerging trends, critical challenges—including interoperability, cybersecurity risks, workforce readiness, and cultural resistance—and best practices adopted by early movers. In response, a comprehensive BM4.0 framework was developed, integrating technologies such as Artificial Intelligence (AI), Internet of Things (IoT), blockchain, robotics, and predictive analytics. The framework encompasses seven interrelated dimensions that collectively provide an actionable roadmap for organizations to accelerate digital transformation, overcome adoption barriers, and sustain long-term competitive advantage. The findings underscore that successful implementation of BM4.0 extends beyond technological adoption and requires strong leadership, strategic alignment, and organizational culture transformation. By consolidating fragmented insights from diverse sources, this study contributes to the literature by offering both a theoretical foundation and practical guidance. Theoretically, it advances management research by positioning digital technologies as key enablers of agility, resilience, and sustainability. Practically, it provides organizations with a structured approach to align digital initiatives with business objectives, key performance indicators, and continuous improvement mechanisms. From a managerial perspective, the study highlights the importance of leadership in driving digital transformation, fostering workforce readiness, and enabling data-driven decision-making through advanced analytics. Despite these contributions, the study has certain limitations. It primarily relies on secondary data, which limits empirical validation of the proposed framework. Additionally, while the BM4.0 framework offers a generalized model, its applicability may vary across industries and organizational contexts. Given the rapid pace of technological advancements, continuous refinement of the framework will be necessary to ensure its ongoing relevance.

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References

Abed, S. Y., & Othman, M. M. (2024, November). *Business excellence for sustainable success: An overview and a proposed model*. In *2024 IEEE International Conference on Technology Management, Operations and Decisions (ICTMOD)* (pp. 1–7). IEEE. https://doi.org/10.1109/ICTMOD63116.2024.10959137

Ahmad, S., Miskon, S., Alabdan, R., & Tlili, I. (2020). Towards sustainable textile and apparel industry: Exploring the role of business intelligence systems in the era of Industry 4.0. *Sustainability, 12*(7), 2632. https://doi.org/10.3390/su12072632

Bagnoli, C., Bravin, A., Massaro, M., & Vignotto, A. (2018). *Business model 4.0: I modelli di business vincenti per le imprese italiane nella quarta rivoluzione industriale*. https://doi.org/10.30687/978-88-6969-286-4

Bali, S., Aggarwal, S., & Sharma, S. (Eds.). (2021). *Industry 4.0 technologies for business excellence: Frameworks, practices, and applications*. CRC Press. https://doi.org/10.1201/9781003140474

Bordeleau, F. E., Mosconi, E., & de Santa-Eulalia, L. A. (2020). Business intelligence and analytics value creation in Industry 4.0: A multiple case study in manufacturing medium enterprises. *Production Planning & Control, 31*(2–3), 173–185. https://doi.org/10.1080/09537287.2019.1631458

Chaudhary, D., Banerji, J., & Bhati, R. (2025). Determinants of ethical and scalable AI for the sustainable development goals: A qualitative framework from the Global South. *SGS-Humanities & Management, 1*(2). https://www.spast.org/index.php/sgshm/article/view/5348

Choudhary, D., & Nandy, I. (2024). A study of sustainability risks from Industry 4.0 perspective: Taxonomy and future research avenues. *Competitiveness Review: An International Business Journal, 34*(6), 1178–1205. https://doi.org/10.1108/CR-11-2023-0277

Fajsi, A., Morača, S., Milosavljević, M., & Medić, N. (2022). Project management maturity and business excellence in the context of Industry 4.0. *Processes, 10*(6), 1155. https://doi.org/10.3390/pr10061155

Ferdowsian, M. C. (2016). Total business excellence—A new management model for operationalizing excellence. *International Journal of Quality & Reliability Management, 33*(7), 942–984. https://doi.org/10.1108/IJQRM-08-2014-0109

Gomaa, A. H. (2025a). Lean 4.0: A strategic roadmap for operational excellence and innovation in smart manufacturing. *International Journal of Emerging Science and Engineering (IJESE), 13*(4), 1–14. https://doi.org/10.35940/ijese.D2592.13050425

Gomaa, A. H. (2025b). LSS 4.0: A conceptual framework for integrating Lean Six Sigma and Industry 4.0 for smart manufacturing excellence. *Indian Journal of Management and Language, 5*(1), 8–29. https://doi.org/10.54105/ijml.H1810.05010425

Gomaa, A. H. (2025c). Maintenance 4.0: Optimizing asset integrity and reliability in modern manufacturing. *International Journal of Inventive Engineering and Sciences (IJIES), 12*(2), 18–26. https://doi.org/10.35940/ijies.B1098.12020225

Gomaa, A. H. (2025d). SCM 4.0: A conceptual framework for integrating Lean Six Sigma and Industry 4.0 for smart manufacturing excellence. *International Journal of Management and Humanities, 11*(8), 24–44. https://doi.org/10.2139/ssrn.5203692

Gomaa, A. H. (2025e). Smart maintenance in Industry 4.0: Optimizing equipment performance through digital twins and Lean Six Sigma integration. *IUP Journal of Mechanical Engineering, 18*(1), 7–31. https://doi.org/10.71329/IUPJMECH/2025.18.1.7-31

Gomaa, A. H. (2025f). RCM 4.0: A novel digital framework for reliability-centered maintenance in smart industrial systems. *International Journal of Emerging Science and Engineering, 13*(5), 32–43. https://doi.org/10.35940/ijese.E2595.13050425

Henriquez, R., Muñoz-Villamizar, A., & Santos, J. (2023). Key factors in operational excellence for Industry 4.0: An empirical study and maturity model in emerging countries. *Journal of Manufacturing Technology Management, 34*(5), 771–792. https://doi.org/10.1108/JMTM-09-2022-0330

Jankalová, M., & Jankal, R. (2020). How to characterize business excellence and determine the relation between business excellence and sustainability. *Sustainability, 12*(15), 6198. https://doi.org/10.3390/su12156198

Kohtamäki, M., Leminen, S., & Parida, V. (2024). Conceptualizing digital business models (DBM): Framing the interplay between digitalization and business models. *Technovation, 133*, 103013. https://doi.org/10.1016/j.technovation.2024.103013

Lopes, J., Braga, J., & Santos, M. F. (2021). Adaptive business intelligence platform and its contribution as support in the evolution of Hospital 4.0. *Procedia Computer Science, 184*, 905–910. https://doi.org/10.1016/j.procs.2021.04.016

Marques, R., Moura, A., & Teixeira, L. (2020, August). Decision support system for the Industry 4.0 environment: Design and development of a business intelligence tool. In *Proceedings of the International Conference on Industrial Engineering and Operations Management*. https://www.ieomsociety.org/detroit2020/papers/385.pdf

Popkova, E. G., & Sergi, B. S. (2020). Human capital and AI in Industry 4.0: Convergence and divergence in social entrepreneurship in Russia. *Journal of Intellectual Capital, 21*(4), 565–581. https://doi.org/10.1108/JIC-09-2019-0224

Raddi-Mira, L. H., Pecora Junior, J. E., & Deschamps, F. (2024). Framework for implementing Industry 4.0 projects. *Sustainability, 16*(6), 2387. https://doi.org/10.3390/su16062387

Rahim, M. J., Islam, M. J., Islam, M. N., & Rahim, M. I. I. (2024). Mediating role in Industry 4.0 (4IR) adoptions and sustainable corporate financial growth in developed economies. *Journal of Governance and Accountability Studies, 4*(2), 121–145. https://doi.org/10.35912/jgas.v4i2.2511

Ram, M. A., & Yasin, A. S. (2025). A study of risk management policy and practices at Bajaj Finance Ltd. *International Journal of Research Studies on Environment, Earth, and Allied Sciences (IJRSEAS), 2*(5), 1–9. https://eesrd.us/wp-content/uploads/020501.pdf

Rincon-Guio, C., Hernández-Ramírez, J., Martínez, C. M. O., Ponce, M. S. P., Baque-Cantos, M. A., Santistevan-Villacreses, K. L., et al. (2023). A systematic literature review on advances, trends, and challenges in project management and Industry 4.0. *LogForum, 19*(2). https://doi.org/10.17270/J.LOG.2023.884

Sergi, B. S., Ključnikov, A., Popkova, E. G., Bogoviz, A. V., & Lobova, S. V. (2022). Creative abilities and digital competencies for transitioning to Business 4.0. *Journal of Business Research, 153*, 401–411. https://doi.org/10.1016/j.jbusres.2022.08.026

Setyadi, A., Soekotjo, S., Lestari, S. D., Pawirosumarto, S., & Damaris, A. (2025). Trends and opportunities in sustainable manufacturing: A systematic review of key dimensions from 2019 to 2024. *Sustainability, 17*(2), 789. https://doi.org/10.3390/su17020789

Sudirman, N. (2025). Digital entrepreneurship and business innovation: Strategies for Indonesian SMEs in the era of Industry 4.0. *Journal of Indonesian Scholars for Social Research, 5*(1), 24–34. https://doi.org/10.59065/jissr.v5i1.170

Tavera Romero, C. A., Ortiz, J. H., Khalaf, O. I., & Ríos Prado, A. (2021). Business intelligence: Business evolution after Industry 4.0. *Sustainability, 13*(18), 10026. https://doi.org/10.3390/su131810026

Vrchota, J., Řehoř, P., Maříková, M., & Pech, M. (2020). Critical success factors of project management in relation to Industry 4.0 for sustainability of projects. *Sustainability, 13*(1), 281. https://doi.org/10.3390/su13010281

Yusriadi, Y., Awaluddin, M., Firman, H., & Asrijal, A. (2022). Implementation of e-commerce in supply chain management. *Uncertain Supply Chain Management, 10*(4), 1279–1288. https://doi.org/10.5267/j.uscm.2022.7.012

Zapletalová, Š. (2023). Business excellence models and business strategy. *Total Quality Management & Business Excellence, 34*(1–2), 131–147. https://doi.org/10.1080/14783363.2022.2033615