

Overcoming the Challenges and Obstacles in the Implementation of 4.0 in the Supply Chain of the Pharmaceutical Industry

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ABSTRACT

This qualitative study explores the context-specific challenges influencing the adoption of Industry 4.0 (I4.0) in pharmaceutical supply chains in Pakistan, a developing economy with a distinct regulatory environment. Building on prior research, the study examines the complex socio-technical dynamics associated with I4.0 adoption, drawing on participants' experiences and perspectives. Data was collected through semi-structured interviews with supply chain professionals from four major pharmaceutical firms and analyzed using thematic analysis in NVivo. The findings indicate that human and organizational factors—such as resistance to change among experienced staff and limited middle-management engagement—were perceived as significant challenges, often influencing adoption experiences more strongly than financial or technological considerations. Participants also highlighted a cyclical dependency in which unclear government digital roadmaps and limited public investment hinder corporate adoption, reinforcing skills and infrastructure gaps. Based on these insights, the study proposes a context-sensitive action framework linking identified drivers and multidimensional challenges to targeted interventions. The framework provides practical guidance for managers while offering a nuanced understanding of I4.0 adoption processes in the Pakistani pharmaceutical sector.

Keywords - Industry 4.0 Adoption, Technology–Organization–Environment (TOE) Framework, Pharmaceutical Supply Chain, Socio-Technical Challenges, Change Management, Emerging Economies, Digital Transformation

1. INTRODUCTION

The fourth industrial revolution, or Industry 4.0 (I4.0), represents a profound paradigm shift in manufacturing and supply chain management, characterized by the integration of cyberphysical systems, the Internet of Things (IoT), big data analytics, and artificial intelligence (AI) (Peres et al., 2020). Industry 4.0 was originally presented as a strategic government initiative in Germany to drive digitalization in industrial fabrication, aiming to enhance the competitiveness of the manufacturing sector (Kagermann et al., 2013). This transformation promises to create "smart" factories and supply chains capable of real-time optimization, predictive maintenance, and unprecedented levels of transparency and efficiency (Frank et al., 2019; Zheng et al., 2018). For high-stakes, regulation-intensive sectors like the pharmaceutical industry, the potential benefits of I4.0 are particularly compelling, offering pathways to enhance drug quality, ensure supply chain integrity, accelerate time-to-market, and improve regulatory compliance (Arden et al., 2021).

However, the journey from conceptual potential to operational reality is fraught with significant implementation challenges. Extant literature has catalogued a range of barriers, commonly categorized into technological (e.g., data integration, cybersecurity), economic (e.g., high initial investment, uncertain ROI), organizational (e.g., skills gap, resistance to change), and external

(e.g., regulatory uncertainty, lack of standards) domains (Moktadir et al., 2018; Raj et al., 2020). While these studies provide a valuable foundational understanding, a critical gap persists. Much of this research offers generalized frameworks or focuses on developed economies with advanced technological infrastructures, leaving a lacuna in context-specific investigations, particularly within the dynamic environments of emerging economies (Kumar et al., 2020; Ghobakhloo., 2020).

This context-specific gap is acutely evident in the pharmaceutical supply chain. The industry's unique imperatives—strict Good Manufacturing Practice (GMP) compliance, complex cold-chain logistics, product serialization requirements, and intense regulatory scrutiny—create a distinct set of operational parameters (Arden et al., 2021). Implementing I4.0 here is not merely a technological upgrade but a complex socio-technical transformation that interacts intimately with these existing constraints. Recent studies underscore that the success of such digital transformation is less about the technologies themselves and more about an organization's ability to manage the accompanying change in processes, skills, and culture. Yet, how these challenges manifest, interact, and are prioritized within the specific operational and national context of a pharmaceutical supply chain in an emerging economy remains underexplored.

Focusing on Pakistan as a representative emerging economy, this study addresses this gap. Pakistan's pharmaceutical industry, while robust, operates within a landscape marked by infrastructural constraints, economic volatility, and an evolving regulatory regime. This context amplifies certain challenges and may introduce unique obstacles that are not prominent in Western literature. Therefore, this research is guided by the following primary question: What are the key perceived challenges and obstacles to implementing I4.0 in Pakistan's pharmaceutical supply chain, and what actionable strategies can be formulated to overcome them?

The purpose of this qualitative study is twofold. First, it seeks to explore and interpret the multidimensional challenges—technological, economic, organizational, and political—encountered by Pakistani pharmaceutical firms in their efforts to adopt Industry 4.0 (I4.0) technologies. Rather than relying on decontextualized or generic classifications, the study aims to capture how these challenges are experienced, understood, and interrelated within the local institutional, regulatory, and market context.

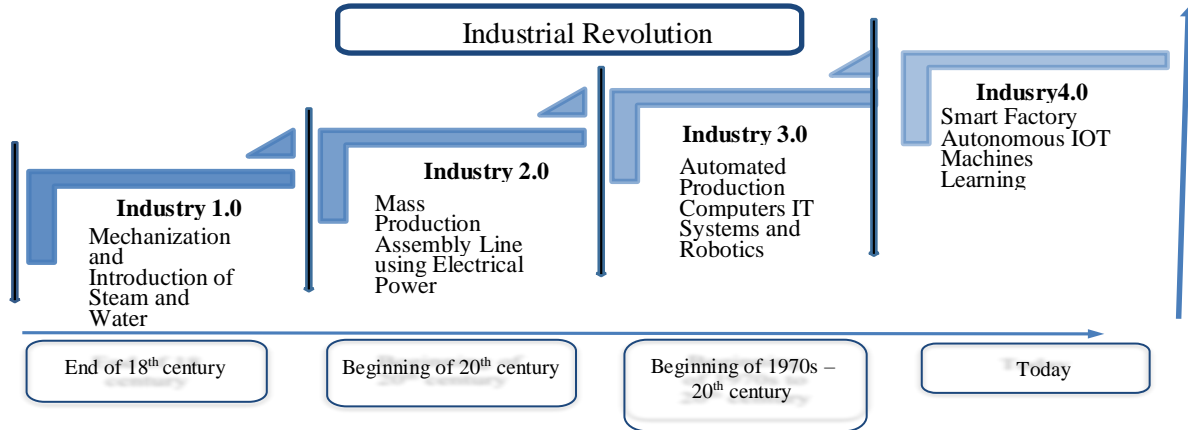
Second, in response to scholarly calls for more prescriptive and practice-oriented research (Wamba et al., 2022; Bai et al., 2020), the study aims to inductively synthesize empirical insights into a coherent, context-sensitive action framework. This framework is intended to articulate how identified drivers and barriers shape firms' digital transformation trajectories and to propose strategic interventions grounded in participants' lived experiences. By doing so, the study aspires to offer theoretically informed and practically relevant guidance for managers and policymakers seeking to navigate and support Industry 4.0 adoption in Pakistan's pharmaceutical sector.

The contribution of this research is significant for both theoretical advancement and practical implementation. Situated within the progression of industrial development (*see Figure 1: Stages of the Industrial Revolution*), it theoretically enriches the I4.0 and digital supply chain literature by providing in-depth, qualitative exploration from an underexplored regional and industrial context, testing the applicability of existing frameworks, and potentially revealing new, context-derived variables. In practice, it offers evidence-based managerial insights and a structured roadmap for supply chain professionals, technology providers, and government agencies in

Pakistan and similar economies, thereby facilitating a more effective and sustainable digital transformation in the healthcare sector.

Figure1.

Stages of Industrial Revolution



Note. From Finance, Audit, Tax Consulting Corporate: Zurich, Swiss, 2015.

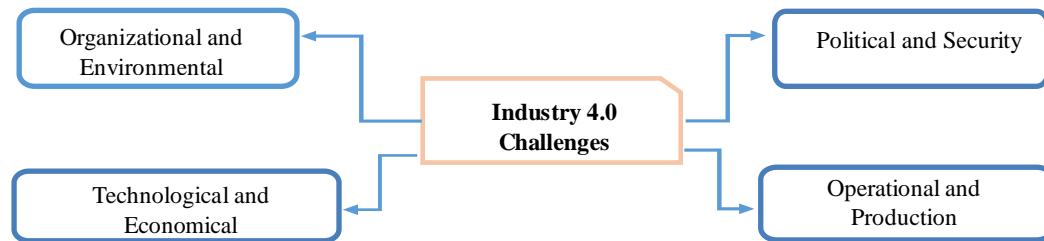
2. LITERATURE REVIEW

Industry 4.0 represents a new phase of the Industrial Revolution, characterized by smart factories that integrate advanced mechanization, predictive maintenance, and self-optimization to enhance productivity (Becker et al., 2011). Foundational studies define Industry 4.0 as the integration of Cyber-Physical Systems, Internet of Things, and cloud computing to create smart factories (Kagermann et al., 2013), a transformation that extends to supply chain management and gave rise to the concept of Supply Chain 4.0 (Frank et al., 2019). The extensive use of sensor-generated data enables real-time visibility of manufacturing assets and predictive maintenance, reducing equipment downtime (Koh et al., 2019). While Industry 4.0 principles are applicable across diverse sectors, this wide applicability also amplifies the complexity and persistence of implementation challenges (Ghadge et al., 2020b).

The pharmaceutical industry has evolved from manual processing to complex, large-scale manufacturing systems, resulting in highly intricate supply chains. This complexity, combined with rapid technological advances such as artificial intelligence and robotics, necessitates adopting Supply Chain 4.0 to enhance agility, regulatory compliance, and operational efficiency (Arden et al., 2021). However, technological implementation remains challenging for small and medium enterprises (SMEs), as it requires skilled human capital and significant financial investment (Haseeb et al., 2019). Moreover, obstacles such as regulatory constraints, workforce resistance, and high implementation costs also hinder the adoption of technology (Neves et al., 2025; Haman et al., 2025). These challenges are further exacerbated by limited absorptive capacity, technical capabilities, and financial resources, increasing reliance on government support and external knowledge collaborations (Issa et al., 2017). These interrelated barriers are systematically categorized in *Figure 2 (Proposed Categorization of Industry 4.0 Implementation Challenges)*.

Figure 2.

Proposed Categorization of Industry 4.0 Implementation Challenges



Note. Author's Contribution.

Although Industry 4.0 enables automation, mass customization, improved decision-making, and resilience against supply chain disruptions, its successful implementation requires substantial strategic effort to overcome these barriers (Demir et al., 2020; Zheng et al., 2018). Firms across industries adopt diverse approaches to digitalization, thereby highlighting the need for sector-specific frameworks that account for unique operational conditions (Büyüközkan & Göçer, 2018). The existing literature identifies a significant research gap in understanding the full spectrum of Industry 4.0 challenges faced by SMEs, particularly the human dimension of digital transformation (Pfohl et al., 2015). While prior studies have explored implementation strategies, few have comprehensively documented the multidimensional obstacles encountered during this adoption, thus validating the need for this research (Masood & Sonntag, 2020). This study categorizes Industry 4.0 challenges into operational, organizational, technological, and political domains, along with security domains (Alaloul et al., 2020a).

This research is grounded in the Technology–Organization–Environment (TOE) framework, which provides a holistic lens for analyzing technology adoption by examining technological, organizational, and environmental contexts (Tornatzky & Fleischer, 1990; Haman et al., 2025). The TOE framework is particularly suitable for this study as it captures the multifaceted nature of Industry 4.0 challenges and allows its application across diverse industrial and national settings (Baker, 2011; Ghobakhloo, 2020; Hsu et al., 2025). In this study, the TOE framework is used to structure the literature review, guide interview design, and, finally, synthesize empirical findings into a coherent action plan that addresses context-specific constraints in Pakistan's pharmaceutical sector.

2.1. Operational and Production Challenges

The transition to automated Industry 4.0 production systems poses significant operational challenges, including high modernization costs, workforce reduction, and a shift toward more complex, information-based job roles (Ghadge et al., 2020b).

An inadequately skilled workforce and complex redesign process are significant barriers to the transition of workforce into the automated, decentralized roles that are required for Industry 4.0 adoption (Moktadir et al., 2018). Major technological hurdles include the integration of RFID for data handling, connecting machinery via the internet, using ICT to recognize production statuses, and the broader introduction of IoT systems (Tan & Sidhu, 2022; Masood & Sonntag, 2020). Consequently, organizations increasingly modify design procedures to achieve lower energy consumption and improved product sustainability, a transition that often results in increased design, coordination, and implementation complexity (Yadav et al., 2020). The lack of effective

reverse logistics systems complicates product reprocessing and the monitoring of sustainability performance, resulting in fragmented and inefficient recovery processes (Mastos et al., 2020). Material damage during transportation significantly disrupts reverse logistics activities (Bag et al., 2021). Auditing standards constrain SSCM implementation due to limited access to advanced data. From the supplier perspective, limited awareness of prevailing sustainability standards for raw materials poses substantial risks (Mastos et al., 2020). Collectively, these operational challenges represent major barriers to Industry 4.0 implementation in supply chain management.

2.2. Organizational and Environmental Challenges

Considering multiple human and environmental factors, several challenges to Industry 4.0 adoption have been identified, particularly the absence of management support (Kumar Mangla & Luthra, 2018). Increasing organizational complexity within manufacturing systems limits the effectiveness of centralized control, necessitating a shift toward decentralized decision-making. Industry 4.0 transformations occur rapidly and demand continuous skill development, training, and development, which are difficult to achieve without robust administrative support (Ghadge et al., 2020a). Another critical challenge is the lack of expertise, as decentralized operations rely on local information, with decisions executed either through artificial intelligence–based tools or by skilled workers (Mian et al., 2020)

Supply chain complexity constrains the implementation of sustainability within the traditional supply chain environment (Yadav et al., 2020). To enable faster decision-making, new procedures are required to address emerging framework requirements, which necessitate reducing rigid organizational hierarchies (Mian et al., 2020). Limited involvement of senior management in sustainability initiatives signals failures in the implementation of sustainable supply chain management (SSCM) (Bag et al., 2021), as administrations often struggle to integrate sustainability into existing supply chain processes (Bag et al., 2021). Active workforce participation in supervisory roles and empowerment enhances productivity and facilitates SSCM adoption, whereas neglecting employee involvement poses challenges to Industry 4.0 implementation. Resistance to cultural change among employees further complicates SSCM adoption during sustainability transitions (Yadav et al., 2020).

2.3. Technological and Economic Challenges

Rapid technological advancement is essential for economic success; however, implementing Industry 4.0 faces several substantial challenges. These include ensuring data quality through standardized connectivity and safeguarding manufacturing systems against increasingly sophisticated cybersecurity threats (Götz & Jankowska, 2020). Moreover, Industry 4.0 technologies require high initial investments to support ethical and sustainable practices (Kumar et al., 2020). The heterogeneous nature of data interpretations further complicates the integration of diverse data sources with divergent semantics for advanced analytics (Götz & Jankowska, 2020). Implementing both Industry 4.0 and sustainability demands significant financial investment across all Industry 4.0 pillars, and insufficient investment leads to multiple supply chain implementation issues (Mian et al., 2020). In addition, inadequate frameworks to ensure robust data security during Industry 4.0 adoption pose serious risks to manufacturing firms (Moktadir et al., 2018). Furthermore, decision-makers often prioritize short-term economic returns when adopting sustainable supply chains, limiting long-term commitment (Yadav et al., 2020). Finally, limited financial, technical, and human resources significantly increase the risks associated with sustainability implementation in complex supply chain environments. (Götz & Jankowska, 2020).

2.4. Political and Security Challenges

The widespread adoption of interconnected and computerized manufacturing systems under Industry 4.0 has significantly increased exposure to cybersecurity threats. Across the value chain, large-scale data transactions intensify risks related to data security, confidentiality, and system integrity, making cybersecurity a critical concern in Industry 4.0 implementation (Ghadge et al., 2020a). A severe deficiency in information security capabilities persists among both individuals developing digital processes and those responsible for protecting digital infrastructures (Mentsiev et al., 2020).

Industries leading the Fourth Industrial Revolution increasingly recognize security as a strategic priority (Mentsiev et al., 2020). However, a major challenge arises from accountability issues in cybersecurity governance, as smart products interact with multiple stakeholders, creating ambiguity over who is responsible in the event of a security breach (Trehan et al., 2022). Such liability concerns pose significant barriers to the effective implementation of Industry 4.0.

Viruses and cyber-attacks can severely disrupt Industry 4.0 operations, potentially shutting down advanced manufacturing systems at substantial cost. The integration of IoT devices, services, human actors, and data further increases vulnerability to data theft, industrial espionage, and cyber intrusions within Industry 4.0-enabled supply chains (Manasa & Joseph, 2023).

2.5. Motives & Driving Forces that Expedite the Prevailing Challenges

The barriers to implementing Industry 4.0 in supply chain management provide a critical foundation for understanding the need for deliberate, sustained development of supply chain practices. Multiple driving forces across sectors accelerates these challenges. A key obstacle to sustainability adoption in supply chains is the coexistence of internal limitations—such as inadequate training, insufficient knowledge, weak IT integration, and poor organizational structures—alongside external pressures, including low supplier commitment and market uncertainty (Walker et al., 2008).

As firms adopt advanced technologies, deficiencies in employee training, limited awareness of integrated systems, weak internal IT integration, and ineffective organizational structures heighten operational risks and uncertainty, forcing firms to compete under increasingly complex conditions. Moreover, the lack of supplier commitment further intensifies Industry 4.0 implementation challenges within supply chains, creating significant execution barriers (Gopal & Thakkar, 2016). Additional drivers include ineffective reverse logistics systems, insufficient government investment, and the absence of secure information infrastructures, all of which exacerbate implementation difficulties (Mian et al., 2020).

The primary objective of Industry 4.0 implementation in supply chains is to digitally integrate operations, reduce forecasting errors, and enhance productivity, efficiency, and flexibility (Hofmann & Rüsç, 2017). Organizations further pursue advanced capabilities such as product customization, improved supplier collaboration, intelligent warehousing, and optimized vehicle routing through Industry 4.0 adoption (Ghobakhloo, 2020).

Overall, key implementation barriers—namely skills gaps, weak IT integration, and limited supplier commitment—constrain Industry 4.0 adoption across operational, organizational, technological, and political dimensions. This study addresses these challenges by proposing an actionable framework emphasizing infrastructure readiness, workforce development, government support, and secure automation systems.

2.6. Overcome Challenges of Supply Chain 4.0 in the Pharmaceutical Industry

This framework provides valuable managerial insights by clarifying the technological requirements and benefits of Industry 4.0, thereby reducing uncertainty surrounding its implementation (Dalenogare et al., 2018). It enables managers to adopt a holistic perspective by emphasizing both front-end and foundational technologies that support Industry 4.0 adoption and by serving as a maturity model to guide phased implementation (Saucedo-Martínez et al., 2018). The framework further outlines technology-specific strategies aligned with varying levels of implementation complexity, supporting informed decision-making (Kamble et al., 2018).

From a practical standpoint, the proposed framework offers an actionable roadmap to address Industry 4.0 implementation challenges and enhance supply chain transparency, cost efficiency, collaboration, and warehouse agility (Salkin et al., 2018). Effective adoption requires coordinated efforts, including the development of technological infrastructure and skilled workforces at the organizational level, complemented by government support and policy incentives (Kiel et al., 2017).

Operationally, Industry 4.0 adoption necessitates automation, smart warehousing, and real-time visibility supported by robust cybersecurity and enabling regulatory environments (Luthra et al., 2018). Intelligent Warehouse Management Systems (WMS), combined with advanced analytics, artificial intelligence, and machine learning, facilitate optimized inventory management, improved delivery performance, and automated logistics operations. In parallel, effective management of complex supplier networks and active partner engagement remain critical for overcoming persistent supply chain challenges and enhancing customer satisfaction and sales performance (Whysall et al., 2019).

3. RESEARCH METHODOLOGY

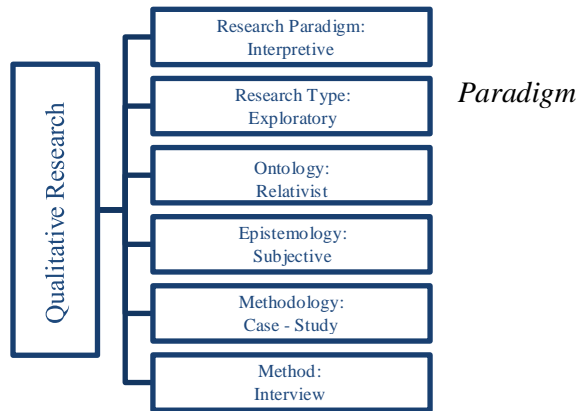
Qualitative research enables an in-depth exploration of social phenomena by examining individuals' and groups' experiences, behaviors, and contextual realities from their own perspectives (Shareia & Engineering, 2016; Abbott et al., 2018). Given the complexity of Industry 4.0 implementation, qualitative inquiry is particularly appropriate, as it prioritizes depth of understanding over numerical measurement while acknowledging practical constraints related to time, resources, and researcher effort (Bengtsson, 2016). Accordingly, this study adopts a qualitative methodology to examine Industry 4.0 implementation challenges in supply chains and the organizational responses to them, drawing on secondary qualitative sources, including academic literature and documented case studies.

This study investigates complex, context-specific issues of Industry 4.0 adoption within real-world organizational settings, using semi-structured interviews as the primary data collection method (Zainal, 2007; Cousin, 2005). Aligned with the philosophical foundations of the exploratory research paradigm (*see Figure 3: Philosophical Fundamentals of Paradigm*), this approach is particularly suitable when phenomena are not clearly bounded and must be examined within their natural organizational and institutional contexts (Alaarij et al., 2015; Toloie-Eshlaghy et al., 2011).

Semi-structured interviews enable participants to provide rich, experiential insights into the “how” and “why” of I4.0 adoption, while maintaining a flexible structure that allows exploration of emergent themes. The research is guided by an exploratory paradigm encompassing ontology, epistemology, methodology, and methods, ensuring coherence between the study's philosophical

assumptions and qualitative inquiry strategy (Butina et al., 2015; Gustafsson, 2017; Toloie-Eshlaghy et al., 2011).

Figure 3.
Philosophical Fundamentals of

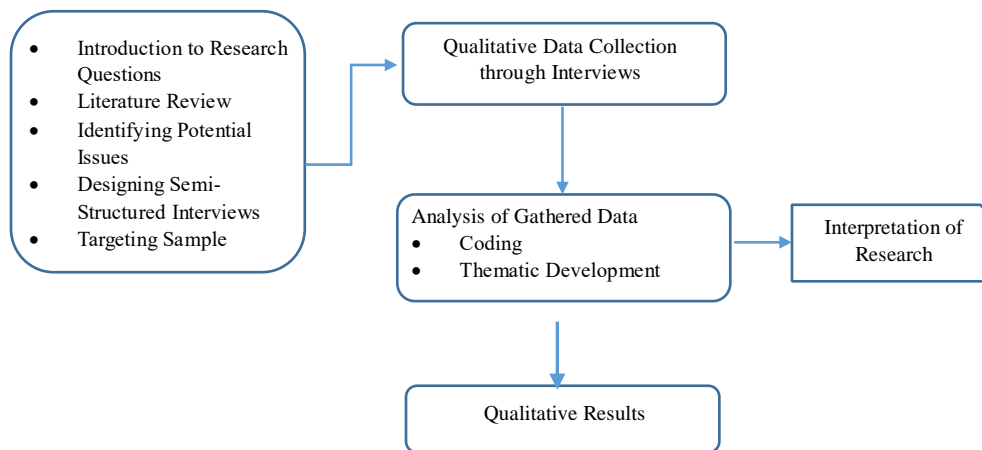


Note. Author's Contribution

This study adopts an idealist ontology, which assumes that reality is socially constructed and understood through individuals' subjective experiences. From this perspective, the social world is interpreted based on participants' personal perceptions and meanings rather than an objective external reality (Scotland, 2012).

Philosophically, the study adopts an idealist ontology, viewing reality as socially constructed and understood through participants' subjective experiences (Scotland, 2012). It is underpinned by a subjectivist epistemology, where knowledge is generated through individuals lived experiences and interpretations of observed phenomena (Malterud, 2016). The theoretical perspective reflects how individuals view and make sense of the world (Gaya & Smith, 2016) and, in this study, is grounded in interpretivism, which emphasizes inductive reasoning by moving from participants' qualitative insights toward broader conceptual understanding rather than relying on quantitative measurement (Scotland, 2012; Flick, 2004). Interpretivism, therefore, focuses on meaning, consciousness, and interpretation within participants' own frames of reference, making it appropriate for examining complex organizational and social phenomena where context is central (Kamal, 2019). The summary of the study's research activities is presented in *Figure 4*.

Figure 4.
Summary of Research Activities



Note. Author's Contribution.

3.1. Research Design

This empirical study adopts a qualitative, exploratory design to address the research question: What are the key perceived challenges to implementing Industry 4.0 (I4.0) in Pakistan's pharmaceutical supply chain, and what actionable strategies can address them? The study focuses specifically on the Pakistani context, where empirical evidence is limited, and seeks to develop a contextual framework to address this research gap. The findings contribute to understanding I4.0 implementation challenges, offer practical value to pharmaceutical firms adopting digital supply chain systems, and extend the existing body of knowledge in Pakistan.

A qualitative approach enables in-depth exploration of complex, context-dependent phenomena. Given the early stage of I4.0 adoption in the sector, an exploratory design is appropriate for identifying key issues rather than testing predefined hypotheses. Semi-structured interviews with experts from four pharmaceutical firms were conducted to capture rich, context-specific insights, enabling the identification of recurring challenges, patterns, and differences across organizations. This approach strengthens analytical depth and explanatory power and directly supports addressing the "what" and "how" dimensions of the research question, informing the development of actionable strategies for I4.0 implementation.

3.2. Qualitative Data Collection

Drawing on an extensive review of prior studies, this research identified critical gaps and the need to examine key challenges and obstacles in implementing Industry 4.0 (I4.0) within supply chains (see Sections 1 and 2). The literature informed the development of open-ended, semi-structured interview questions to capture expert insights into these challenges.

The interviews followed a pre-designed question framework comprising three sections: (1) general questions about the research phenomenon and the interviewee's role, (2) targeted questions on identified themes such as I4.0 implementation challenges in supply chains, and (3) participants' perspectives on potential improvement strategies. A standardized interview protocol ensured consistency while allowing flexibility for exploratory discussion. Interviews were conducted primarily face-to-face at participants' offices, with one interview conducted virtually. Each interview lasted between 45 and 75 minutes, with an average duration of approximately 60 minutes. All interviews were conducted in English, audio-recorded with prior consent, and supported by field notes to document contextual and nonverbal observations.

Semi-structured interviews are widely recognized as an effective qualitative data collection method due to their flexibility and capacity to explore emerging themes (Kallio et al., 2016; Magaldi & Berler, 2020). This approach allowed participants to elaborate on issues they considered most significant, facilitating deeper exploration of experiences, perspectives, and contextual realities (Sauer et al., 2010). Interview guides were shared with participants in advance to address data-sensitivity concerns and to allow clarification or exclusion of topics deemed inappropriate.

The study adhered to strict ethical standards throughout data collection. Formal approval was obtained prior to conducting interviews, and informed consent was secured from all participants. Interviewees were provided with an information sheet detailing the study's purpose, voluntary participation, confidentiality measures, and the right to withdraw at any stage. To ensure anonymity, all identity-revealing details were removed during transcription, and the data were securely stored on password-protected devices accessible only to the research team.

3.3. Sample Selection

Sample selection is a critical element of qualitative research, as it must align closely with the study's research questions, themes, and objectives. Accordingly, this study employed purposive, criterion-based sampling, targeting experts within the pharmaceutical supply chain sector, as only individuals operating in this domain can provide relevant and informed insights (Marshall, 1996). Purposeful sampling prioritizes selecting information-rich cases, which, while potentially biased in quantitative research, represents a methodological strength in qualitative inquiry by emphasizing depth, relevance, and contextual understanding.

Firm selection was guided by three criteria: (1) medium-to-large registered pharmaceutical manufacturers in Pakistan, (2) the presence of formal supply chain departments, and (3) active engagement in digitalization initiatives. Four firms meeting these criteria were selected, offering variation in market positioning. Interviewees were required to hold managerial or senior specialist roles, have at least five years of industry experience, and be directly involved in digitalization-related decision-making.

The sample size was determined using the principle of data saturation, which was achieved when no new insights or themes emerged. After analysis of interviews from the fourth firm, recurring patterns—such as resistance to change, infrastructural constraints, and financial limitations—were consistently observed, indicating saturation. To enhance credibility and validity, the study employed triangulation, integrating multiple perspectives and sources to reduce bias and provide a balanced, context-rich understanding of the phenomenon (Natow, 2020; Noble & Heale, 2019; Renz et al., 2018).

3.4. Data Transcription

In qualitative research, transcription constitutes the first critical step in data analysis, enabling systematic examination of interview data and identification of themes and patterns. Transcribed data facilitate keyword searches, anonymization, framework development, and the extraction of illustrative evidence, despite transcription being a time-intensive process (Renz et al., 2018).

All interviews conducted with pharmaceutical firms were transcribed verbatim to ensure accuracy and data integrity. Interviews served as the primary data source, while secondary data, including academic literature, company documents, and publicly available reports, were used to support triangulation. To capture multidimensional perspectives, multiple interviews were conducted across case firms. All transcripts and observational notes were imported into NVivo 12 and analyzed using thematic analysis to support theory and framework development.

During the initial familiarization and coding phase, two researchers independently conducted open coding on a subset of transcripts. Coding frameworks were compared, discrepancies were discussed, and a consensus-based codebook was developed to enhance inter-code reliability. This finalized codebook was subsequently applied to the full dataset by the primary researcher. In the theme development stage, the research team iteratively clustered codes based on conceptual similarity, reviewed them, and refined them to ensure alignment with the research question.

NVivo was selected due to its effectiveness in analyzing unstructured qualitative data, including interview transcripts and documents, thereby improving analytical efficiency and accuracy. Theme validation was achieved through triangulation, comparing emergent themes with secondary sources and revisiting the raw data to ensure representativeness. Data saturation was confirmed when no new codes or themes emerged from the final interviews, indicating comprehensive

coverage of implementation challenges. Triangulation further strengthened credibility by contextualizing findings within historical and organizational evidence (Renz et al., 2018).

3.5. Background of Sample Pharmaceutical Companies

Data was collected from four pharmaceutical industries in Pakistan:

- Nova-Med Pharmaceuticals
- Remington Pharmaceuticals
- Global Pharmaceuticals
- CCL Pharmaceuticals

i CCL Pharmaceuticals

CCL Pharmaceuticals is a multinational company with over 50 years of experience and operations in 14 countries across Asia and Africa. It offers over 200 products and maintains its market leadership through a high-performance culture that encourages innovation. The company is committed to quality and stakeholder impact, underpinned by a comprehensive Quality Management System that ensures the delivery of safe, compliant products.

ii Nova-Med Pharmaceuticals

Nova-Med Pharmaceuticals, established in 2003, is a major Pakistani manufacturer serving national and multinational clients. While it operates under strict DRAP regulations and maintains ISO and CGMP certifications to ensure quality, it faces challenges from market competition, inflation, and a weak national economy. The company's mission is to improve human life by developing high-quality medicines.

iii Remington Pharmaceuticals

Remington Pharmaceuticals is a top 20 Pakistani company with over 30 years of experience. It operates as one of the country's largest and most modern CGMP-compliant facilities, producing a wide range of products like tablets, syrups, and ophthalmics. Its commitment to international quality standards (US FDA, MHRA) and a strong R&D team has established it as a market leader and a benchmark for quality in the industry.

iv Global Pharmaceuticals

Established in 1995, Global Pharmaceuticals has grown from an importer into a top 20 Pakistani manufacturer. It is currently a rapidly growing company investing in IoT technology. Its stable market position is supported by a portfolio of branded generics and a team focused on exceeding customer expectations.

4. FINDINGS AND ANALYSIS

All the data was collected through interviews with four pharmaceutical companies to identify the advantages and barriers to implementing Industry 4.0 and modern technology. It has discussed the objectives of implementing the latest technology. The managers and owners of organizations highlighted several key points. The following are the main focus points of this analysis.

- Effective Risk Management
- Coordination and Leadership
- Impact and Importance of Disruptive Technologies

- Company's Infrastructure
- Communication Issues

4.1. Objectives of Industry 4.0

From the data collection and findings, several objectives of Industry 4.0 were identified. Despite its benefits and opportunities, firms face substantial implementation hurdles. Key barriers include ineffective reverse logistics systems, lack of government investment, insecure information systems, insufficient training, weak IT integration, limited technological knowledge, poor organizational structures, low supplier commitment, competition, and uncertainty, all of which impede Supply Chain 4.0 adoption.

A supply chain executive from Firm A stated that *“every company has a certain amount of budget in which they have to manage all of their processes happening inside and outside of the firm,”* highlighting financial constraints as a major challenge. Similarly, the Head of Supply Chain at Firm B noted, *“currently we are at about 20% automation, and still, there is a gap of 80%,”* indicating that low automation levels and slow production emphasize the need for optimization through Industry 4.0 technologies.

Resource limitations were also highlighted. A supply chain officer from Firm C mentioned that *“resource-related issues while implementing the SAP technology were another hurdle,”* indicating that advancing organizational resources remains a key objective. An Assistant Manager from Firm D emphasized the importance of technological adoption, stating, *“Any organization that doesn't develop itself with the technology stays behind,”* stressing the need to remain aligned with market trends and customer expectations.

Several key themes emerged from the interviews regarding Industry 4.0 adoption in Pakistani pharmaceutical firms. Data authenticity and security were frequently mentioned as important benefits of implementing advanced technologies. For instance, one expert highlighted that digital systems could improve data reliability, support systematic workflows, and enhance forecasting capabilities, illustrating how firms perceive I4.0 as a tool for better decision-making.

Resistance to change was another recurrent theme across multiple participants. Several managers noted that employees' attachment to traditional methods and reluctance to learn new technologies can hinder adoption, despite their existing experience being valuable to the organization.

Participants also identified potential competitive advantages associated with Industry 4.0, including enhanced transparency, deeper data analysis, increased productivity, and improved data security. However, change management challenges were emphasized consistently, with managers stressing the need for awareness programs and leadership-driven initiatives to foster trust in digital systems and reduce reluctance toward replacing manual processes.

Overall, the findings reflect patterns observed across multiple firms rather than isolated statements, highlighting both the opportunities and challenges of I4.0 adoption in the sector

Operational improvements were also observed. A supply chain planner from Firm C stated, *“The company is moving toward automated resource planning in which we are reducing our labor cost and time.”* Similarly, an operational manager from Firm D reported reduced paperwork and a shift toward paperless operations through software adoption. The importance of structured planning was emphasized by the replenishment manager of Firm B, who noted that *“the company will be needing a proper plan for implementation, as still people in our industry are not ready to accept*

the change.” These insights reflect both the opportunities and challenges of I4.0 adoption in the sector (see Figure 5: Objectives of Industry 4.0).

Figure 5.
Objectives of Industry 4.0



Note. Author's Contribution

Overall, the findings indicate that behavioral change, technological awareness, supplier integration, and structured planning are central objectives of Industry 4.0 implementation.

4.2. Risk Management

Data management plays a critical role in industrial growth and competitiveness. To minimize the risk of data loss and maintain operational efficiency in a fast-paced business environment, firms increasingly rely on specialized software solutions. In the studied organizations, software development is outsourced to third-party vendors, with firms specifying their system requirements during development and requesting subsequent modifications or enhancements as needed (Interview A). A major challenge in effective risk management relates to the limited accessibility of organizational leadership to software systems controlled by external vendors. As noted by a manager from Firm A, system issues and software bugs are addressed exclusively by the vendor, restricting managerial control. This challenge is further compounded in multinational operations, where software functionalities may perform inconsistently across different countries due to contextual or regulatory differences. In such cases, local management lacks direct authority to resolve issues originating outside their operational jurisdiction (Firm A Manager). Data visibility and unauthorized access represent additional critical risks. To mitigate these concerns, organizations prioritize data protection strategies, including systematic backup mechanisms. As a manager from Firm B emphasized, firms maintain regular data backups to ensure full data recovery in the event of system failure or data loss (Firm B Manager).

Several employees exhibit limited technical proficiency and resist adopting advanced technologies such as SAP, citing perceived difficulties with learning new systems and a lack of confidence in their ability to adapt. To mitigate these challenges, organizations have employed support staff to compile and update data for such employees. As explained by a manager from Firm C, Remote Desktop Connections (RDC) are implemented across all systems, enabling automatic data updates at regular intervals. This approach ensures secure data backup and facilitates seamless integration with SAP, thereby supporting data recovery in the event of system disruptions (Firm Manager C).

Effective coordination between leadership and employees further strengthens data management practices. Supportive and collaborative leadership enhances problem resolution by actively engaging employees to address operational challenges. As highlighted by a manager from Firm D, organizational leadership maintains close collaboration with staff, fostering open communication and collective problem-solving to improve system usage and performance (Firm Manager D).

Risk management refers to the systematic process of identifying, assessing, and controlling threats that may affect an organization's capital, operations, and strategic objectives. These risks may arise from financial uncertainty, legal exposure, technological vulnerabilities, managerial decisions, operational disruptions, or external shocks such as natural disasters. Effective risk management frameworks enable organizations to evaluate interconnected risks and understand their cascading effects on long-term strategic goals. An effective risk management program must be strategically embedded within organizational decision-making, beginning with a clearly defined risk appetite that distinguishes acceptable risks from those requiring mitigation. In an increasingly complex environment shaped by globalization, digital transformation, and climate change as a threat multiplier, strategic risk management has become essential for organizational resilience and sustainable performance.

4.3. Coordination and Leadership

Supportive leadership plays a vital role in managing daily operations, including legal, accounting, and general management, and in facilitating organizational advancement. Leadership support enhances awareness and encourages progressive steps toward technological adoption. As noted by an interviewee from Firm A, "Currently, the level of awareness is good, and leadership is playing a major role in it, supporting us in progressive steps."

The pharmaceutical sector is subject to strict regulation by the Drug Regulatory Authority of Pakistan, requiring firms to comply with mandated technological changes. A respondent from Firm B stated, "team members were manually detecting metal while tablet manufacturing, but later the market was invaded with an automatic machine, and we had to use that at any cost as per the government regulations," highlighting leadership's role in ensuring regulatory compliance. Leadership motivation and respect for employees' ideas were identified as critical factors for technology adoption. A supply chain manager from Firm C stated, "leaders are very cooperative... we are holding time-to-time training for the awareness and understanding of technological advancement by sharing the pros and cons along with practical application data." Similarly, a manager from Firm C emphasized that "no firm can expect positive outcomes unless leadership plays a supportive role," highlighting the importance of continuous training and encouragement.

Employees also value a supportive and communicative work environment. A manager from Firm D noted, "We will be very happy that at least he came and discussed things with us," indicating that leadership interaction and positive feedback improve employee motivation and productivity. Without supportive leadership, organizational growth becomes difficult. Coordination is essential in balancing individual differences and promoting teamwork. Differences in individual needs may conflict with organizational goals. However, coordination harmonizes these goals, enabling effective teamwork and goal achievement. Coordination also supports the development of self-managed teams and knowledge-sharing, enhancing employee competence and organizational responsiveness to competitive environments.

Effective leadership aligns individual efforts toward collective goals by motivating teams and coordinating activities. Leaders provide guidance, accountability, and mentorship, helping employees minimize risks and improve productivity. Regardless of hierarchy, leadership plays a key role in channeling individual capabilities toward organizational excellence.

4.4. Impact of Disruptive Technologies

Rapid technological evolution is transforming work, life, and business through two innovative types: sustaining, which improves existing technology, and disruptive, which creates

significantly more value and radically changes established systems. Successful businesses integrate customers and suppliers into their improvement processes, using these external relationships to boost competitiveness. Lean production further supports this by helping supply chains reduce waste and achieve sustainability (Salkin et al., 2018).

“Technology always creates ease for humans, so the main purpose of performance measurement is to provide valuable information which helps the organization to achieve its strategic goals” (Firm A manager). Technology plays its role in a very smart way; for instance, we get real-time information. It will become much easier for organizations to make decisions, allowing us to identify loopholes and improve things. “Let’s suppose the latest technology in the world now is moving toward less human involvement and real-time transparency, thus, enabling companies to respond more swiftly to disruption and minimizing risk” (Firm A supply chain head). The various aspects of Industry 4.0 help organizations investigate data more deeply and increase transparency. It enables the long-term recording of large amounts of data, and its use and distribution can be easily tracked. “In a supply-chain network, we can easily get to know the phase under which a product is residing. It also elaborates on the time, cost, and resources required from collecting raw materials to delivering finished goods to the end users” (Interview B).

Although such technologies offer many benefits, such as high visibility, point tracking, and tracing of all processes at control points. It increases the supply chain measurement, so many contract manufacturing companies would not be interested in implementing this. “It helps to avoid unnecessary costs. It helps track the entire supply chain in real time. Tracking inventory in real time is not easy. It improves inventory accuracy and enables better inventory control and optimization. It also reduces the associated costs” (Firm C). As disruptive technologies of 4.0 bring transparency throughout the supply chain, it will be helpful for all stakeholders to stay on board. This will help reduce lead time and ensure a zero-defect rate. “With the implementation of Industry 4.0, the supply chain performance can be measured to keep track of long-term organizational goals and detect improvement areas. The following metrics can be considered while measuring supply chain performance” (Firm D).

4.5. Importance of Disruptive Technologies

Pakistan continues to face structural and skills-related challenges in supply chain management, including limited awareness of supply chain concepts and uneven technological readiness. Nevertheless, digital technologies are increasingly important for enhancing operational efficiency and mitigating risk. As noted by a manager from Firm A, while domestic operations are relatively well established, gaps persist in international operations due to insufficient portal integration and skills limitations (Firm A Manager).

Technology adoption has significantly improved operational monitoring and transparency. For instance, firms can track temperature conditions in real time during product transportation, ensuring product integrity throughout distribution. As a manager from Firm C emphasized, enterprise systems such as SAP enhanced information transparency by enabling rapid access to integrated data, reducing the need for repeated manual verification across multiple databases (Firm C Manager).

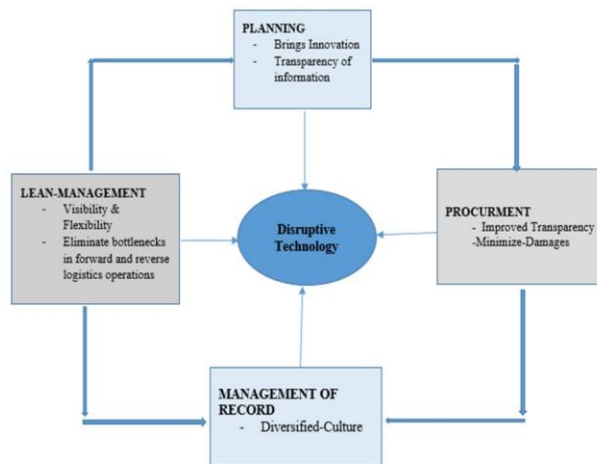
Effective supply chain performance also depends on well-defined organizational policies in logistics, procurement, planning, and warehousing. These functions are coordinated through production and control departments, which determine workforce allocation, process durations, and material flow from raw inputs to finished products. A manager from Firm D explained that detailed

capacity and process calculations enable real-time operational oversight and informed decision-making (Firm D Manager).

Inadequate capacity planning can lead to significant resource inefficiencies. For example, when production capacity is underutilized due to poor planning, organizations incur avoidable operational losses. The integration of data-driven planning tools helps firms align machinery capacity with production targets, thereby optimizing resource utilization and improving overall supply chain performance. These observations reflect the potential benefits of disruptive technologies in addressing capacity-related challenges (*see Figure 6: Output of Disruptive Technology*).

Figure 6.

Output of Disruptive Technology



Note. Author's Contribution

4.6. Company's Infrastructure

A strong company infrastructure helps firms remain competitive in the digital era, where digital transformation and process automation are essential to meet customer demands, respond to market developments, and withstand competitive pressures. Supportive infrastructure enables efficient operations and organizational growth. As noted by a manager from Firm A, “*our leadership is very supportive, the company’s support system helps us to maintain our daily operations, like legal, accounting, and general management,*” allowing firms to use the infrastructure to their advantage.

A robust infrastructure system enables firms to meet increased service demand, particularly during traffic spikes, while ensuring faster and more effective client service. According to a manager from Firm A, “*without a firm’s proper infrastructure, we can’t do things properly because elements of infrastructure provide a proper platform... to make decisions in real time.*” This highlights the importance of infrastructure in supporting timely decision-making and smooth digital interactions.

Company infrastructure and Industry 4.0 implementation are closely interconnected, as advanced infrastructure reduces costs and time while improving efficiency. A replenishment manager from Firm B stated, “*Company infrastructure could have different infrastructures—financial, organizational, IT—which often overlap.*” Inadequate infrastructure limits the successful

implementation of disruptive technologies and may lead to failure even after adoption if systems do not support new processes.

Industry 4.0-driven smart infrastructure promotes higher productivity, connectivity, and growth by making systems simpler, smarter, and more multifunctional. A manager from Firm C noted, *“The world is moving on smart infrastructure as Industry 4.0 makes it possible to generate higher productivity and growth.”* Modern IT systems also support seamless workflows, improved information sharing, reduced downtime, and automated repetitive tasks, enhancing employee productivity and reducing operational stress.

The importance of infrastructure was further emphasized by an operational manager from Firm D, who stated, *“The company’s infrastructure is very important, specifically for the latest technology, as it covers many of the factors, so the company cannot take the risk.”* A stable infrastructure ensures coordination of human resources and operational tools, particularly during unexpected growth. As another respondent from Firm D stated, *“the company’s infrastructure in the implementation of any system or advanced technology plays a role of backbone,”* enabling firms to adapt effectively to evolving market conditions.

4.7. Role of Information Technology (IT)

Advanced information technology plays a significant role in Supply Chain 4.0 by enabling access to real-time data, enabling faster, smarter decision-making, and ensuring effective coordination of business systems and processes. Without a strong IT infrastructure and proper operational support, productivity is not possible. As noted by a respondent from Firm A, *“IT infrastructure’s main goal is to minimize downtime and maintain communication business productivity... efficiently operating the technology helps to improve the linking between components.”* A well-developed IT system that is flexible, secure, and reliable enables organizations to achieve strategic objectives and sustain competitive advantage, whereas poor implementation can lead to productivity losses and security vulnerabilities. A logistics manager from Firm A highlighted that *“IT infrastructure is the backbone of implementing disruptive Supply Chain 4.0 technologies,”* noting that deficiencies in software, internet connectivity, or intranet systems hinder the achievement of automation.

Information technology constitutes a core pillar of Industry 4.0; however, Pakistan faces substantial constraints due to limited support from software service providers and a shortage of skilled IT professionals. A replenishment manager from Firm B observed that *“companies moving toward advanced technologies require a strong IT foundation, but in the Pakistani context, there is a shortage of qualified experts.”* Similarly, another respondent from Firm B highlighted that automation reduces manual work, stating that *“you just have to set the parameters and protocols,”* reinforcing the need for both strong IT infrastructure and skilled personnel.

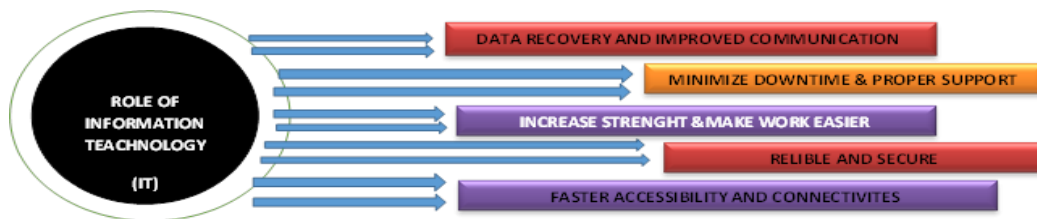
Examples from global firms such as Amazon and Walmart demonstrate how robotics and advanced IT reduce lead times, waste, and improve transparency across production and assembly lines. In contrast, Pakistani firms remain far behind, further emphasizing the importance of IT infrastructure as a prerequisite for adopting disruptive technologies. Infrastructure design ensures that business parameters are measurable and monitored using appropriate devices; any weaknesses in the infrastructure lead to information gaps that undermine Industry 4.0 objectives. A manager from Firm C noted, *“change management is the biggest challenge... secondly, cost-related barriers,”* highlighting financial and behavioral constraints.

Despite these challenges, firms recognize clear benefits. An assistant manager from Firm C stated that Supply Chain 4.0 enables “overseeing various exceptions without the need for any human involvement.” However, successful implementation requires expert trainers and a flexible, secure, and reliable IT infrastructure. Without this foundation, organizations face recurring issues related to connectivity, productivity, and data security.

Overall, IT infrastructure serves as the backbone of Industry 4.0 implementation, enabling accessibility, remote operations, and system integration. It allows organizations to operate efficiently regardless of location, reinforcing its critical role in modern supply chain transformation (see Figure 7: *Role of Information Technology*).

Figure 7.

Role of Information Technology



Note. Author's Contribution.

5. DISCUSSION

This discussion positions the study’s findings within the broader Industry 4.0 (I4.0) literature by identifying areas of convergence, divergence, and contextual insight. Foundational studies outlined the architectural vision of I4.0 and its potential in the supply chain (Kagermann et al., 2013; Frank et al., 2019), while later research documented key implementation barriers (Luthra & Mangla, 2018). Consistent with prior work, high financial costs, cybersecurity risks, and skills shortages remain prominent constraints (Moktadir et al., 2018; Götz & Jankowska, 2020). However, this study provides empirical evidence from an emerging-economy pharmaceutical context, showing that these barriers are interrelated and jointly shape Industry 4.0 implementation rather than operate independently, with their relative importance influenced by contextual conditions.

Although top management support is widely identified as a critical enabler (Kumar et al., 2020), this study reveals a more nuanced barrier: resistance from mid-level and highly experienced operational staff. In environments characterized by entrenched routines, implementation challenges extend beyond executive endorsement to management of socio-technical transitions that disrupt established identities and expertise. This extends the notion of organizational readiness beyond resource availability to include cultural inertia within operational cores. Similarly, while technological infrastructure is often framed as a foundational barrier (Luthra et al., 2018), the findings position it within a cyclical dependency, where infrastructure weaknesses reflect constrained investment driven by regulatory uncertainty and market volatility. This negative lock-in between Environmental and Technological contexts aligns with institutional theory, illustrating how weak institutional support shapes organizational risk perceptions.

In response, the proposed action plan advances a context-sensitive intervention model that explicitly targets this lock-in by prioritizing government policy engagement. Unlike generic frameworks, it identifies the Environmental context as a critical leverage point, demonstrating how

the study moves beyond confirming known challenges to clarify their interdependence and proposing a prioritized response strategy for regulated emerging-market industries.

Further analysis confirms the relevance of all three TOE dimensions while revealing their hierarchical interdependence. Technological barriers—such as legacy system integration, data security, and high investment costs (Götz & Jankowska, 2020)—were frequently framed as consequences of Organizational and Environmental constraints, including unclear regulatory roadmaps and limited internal cost–benefit expertise. Within the Organizational context, the findings highlight the paradoxical role of experienced personnel, who function simultaneously as valuable assets and as agents of resistance. This challenges simplistic views of change resistance and reinforces socio-technical perspectives that link technological adoption with shifts in power, identity, and practice, underscoring the importance of leadership coordination and tailored change management.

The environmental context emerged as a significant constraint, creating a reinforcing cycle in which limited regulatory pressure discourages corporate investment and contributes to persistent skills gaps. This insight extends institutional theory by demonstrating that, in certain settings, deficiencies in one TOE dimension can disable others, effectively stalling adoption. From a performance perspective, integrated technologies remain essential for enhancing productivity, efficiency, communication, and decision-making through automation, data integration, and improved information sharing (Ghobakhloo, 2020; Bai et al., 2020; Raj et al., 2020).

Finally, two counterintuitive findings yield important theoretical and practical implications. First, leadership support alone appears insufficient within deeply entrenched operational cultures, where resistance from experienced personnel constitutes a more substantial barrier than previously assumed. Second, infrastructure deficits function more as symptoms than root causes, with high investment costs closely associated with regulatory ambiguity rather than purely technical limitations. Collectively, these findings indicate a policy-first dependency for technological advancement in highly regulated sectors, shifting responsibility toward industry bodies and policymakers to establish clear “Pharma 4.0” standards as a prerequisite for unlocking sustained corporate investment.

6. Action Plan

Based on the inefficiencies revealed by the empirical findings and data analysis (*see Figure 8*), an action plan is proposed to improve the effectiveness of Reverse Logistics and Industry 4.0 implementation. The proposed recommendations are derived directly from the study’s empirical results and supported by relevant literature on technology adoption and change management.

6.1. Growing Organizational Infrastructure

Organizational structure serves as the internal blueprint of an organization, defining workflows, demonstrating relationships, and coordination mechanisms. An appropriate structure supports operational rationalization and control by clearly assigning authority and responsibility (Kumar et al., 2020). Clear reporting lines improve efficiency by ensuring employees understand their roles, expectations, and accountability from the outset.

A well-designed structure enables departments to align skills and capabilities with tasks, improving integration and coordination across organizational levels (Habibi Rad et al., 2021). It also facilitates performance assessment, as managers can link organizational goals to functional and individual objectives, enabling remedial actions where needed (Matt et al., 2020). Effective

communication channels embedded within the structure further support coordination, task clarity, and employee performance.

6.2. Role of Government

Government intervention plays a critical role in supporting industrial development by fostering entrepreneurship, generating employment, and driving economic growth. Governments contribute through financial support, funding key industries, and implementing protective tariffs, while excessive taxation and regulation may hinder innovation (Kozlov et al., 2019). A balanced regulatory approach is therefore essential.

In pharmaceutical manufacturing, production processes are divided into major and minor stages, both requiring specialized equipment and infrastructure (Poma et al., 2020). Manufacturers frequently allocate resources to low-risk, high-margin products, leading to the under-resourcing of critical, higher-risk outputs, including vaccines. Shared engineering facilities and complex production requirements further complicate compliance with good manufacturing practices, increasing the vulnerability to equipment failure and system fragility (Jayashree et al., 2021).

6.3. Making an Information System Secure

Strong information system security is fundamental to safeguarding organizational data and technological assets. Cybersecurity risks often stem from compromised or weak authentication practices, underscoring the importance of securing devices, networks, and sensitive information with strong, unique access credentials. Limiting access to technological infrastructure to authorized users and essential systems further reduces organizational exposure to cyber threats (Naanani & Education, 2021).

Organizations can minimize system vulnerabilities by restricting unnecessary access to hardware and software resources and by implementing distinct credentials across users, departments, and servers. In addition, employee screening processes, alongside structured cybersecurity training and awareness programs, play a critical role in mitigating risks associated with phishing and social engineering attacks (Salkin et al., 2018). Although cloud computing provides operational efficiency and scalability, sensitive organizational data should be protected through secure internal controls, routine software updates, and continuous monitoring to mitigate risks arising from third-party dependencies.

6.4. Professional Workforce

Workforce development focuses on building the capabilities required for future organizational needs, extending beyond single-skill acquisition to continuous learning and adaptability (Flores et al., 2020). A well-designed workforce strategy enhances productivity, motivation, and employee satisfaction while supporting long-term organizational sustainability (Kiel et al., 2017).

Training initiatives, mentorships, apprenticeships, and strategic partnerships enable targeted skill development and knowledge transfer (Hoyer et al., 2020). Effective mentoring enhances confidence, engagement, and performance, benefiting both employees and organizations. Defining a clear vision, encouraging collaboration, identifying skill gaps, and maintaining effective communication during change are essential to building a strategic workforce (Akyazi et al., 2020). Investment in employee development also strengthens organizational resilience while reinforcing employee commitment.

6.5. Proper Decision-Making

Organizational decision-making entails systematically identifying problems and evaluating and implementing appropriate courses of action to maximize stakeholder value. This process includes problem identification—monitoring conditions to detect performance gaps—and problem resolution, where alternatives are evaluated and implemented (Bai et al., 2020). Effective decision-making enables organizations to adapt, remain competitive, and manage uncertainty, whereas poor decision-making can lead to severe financial and operational consequences (Tuffnell et al., 2019).

Decisions within organizations are typically classified as strategic, tactical, or operational. Strategic decisions taken by top management define the organization's long-term direction and external engagement, shaping its future development (Anderl, 2014). These decisions establish foundational commitments that guide organizational behavior over time.

6.6. Technology Equipped Transport

Pharmaceutical products are highly vulnerable during transportation, making the management of supply chain security risks critical to mitigating potential revenue loss and reputational damage for manufacturers, distributors, and logistics providers. Effective training to detect and prevent product adulteration or diversion during transit is therefore essential.

When developing a validation master plan, it is necessary to account for variability in equipment, personnel skills, and levels of pharmaceutical handling experience. These factors complicate achieving a high confidence level (exceeding 95%) in process validation for controlled logistics environments, particularly for sensitive protein-based products (Alaloul et al., 2020b). As a result, additional in-transit monitoring, procedural controls, visual indicators, and stability testing during distribution become necessary, given the difficulty of attaining high validation confidence. In this context, adopting a strategic approach to logistics and transportation offers clear advantages over a purely transactional approach (Manavalan et al., 2019).

Long-term strategic partnerships with transportation providers foster trust and ensure alignment with the specific requirements of pharmaceutical and biotechnology firms. Such partners typically maintain skilled workforces and invest in advanced temperature validation, tracking, and risk management systems, driven by a mutual commitment and shared objectives related to patient and product safety (Mostafa et al., 2020). In addition, they emphasize quality assurance and continuous improvement, supported by operational transparency, performance metrics, in-transit visibility, and milestone reporting.

Consequently, strategic transportation partners become integrated into their clients' quality management practices, delivering consistency, reliability, and high-quality pharmaceutical distribution. This integration ensures uninterrupted market access and patient availability of life-saving medicines, including during periods of disruption (Yavas et al., 2020). By prioritizing value creation rather than cost minimization alone, such partnerships also support sustainable revenue realization.

6.7. Intelligent Warehousing

In such contexts, intelligent and secure storage solutions assume critical importance. Pharmaceutical products, including tablets, capsules, syrups, and injectable formulations, are highly sensitive to environmental conditions such as humidity and temperature, making storage a significant operational concern. Warehouses must comply with Good Manufacturing Practices (GMP) to ensure product safety, quality assurance, and regulatory compliance. In addition, storage

systems should address risks associated with excess inventory accumulation to prevent supply shortages while ensuring clear visibility of stock levels and product status (You & Feng, 2020).

Failure to modernize warehouse technologies and systems places organizations at a substantial disadvantage and increases the risk of non-compliance with regulatory requirements. The adoption of automated software, cloud-based solutions, and upgraded hardware is therefore essential. An effective warehouse management system enhances inventory control and traceability by providing accurate, real-time stock information, enabling organizations to respond efficiently to customer demand.

Over the long term, these improvements contribute to higher levels of customer satisfaction while reducing operational inefficiencies and avoidable costs arising from process errors, thereby improving profitability (Shahin et al., 2020). Automation also reduces the need for manual record-keeping by digitally maintaining receipts, packing lists, and reports. Furthermore, reconfiguring end-to-end processes—from order processing to final delivery—improves delivery reliability and product availability, ultimately reducing customer complaints and enhancing overall service quality.

6.8. Building Structures for Emerging Industry 4.0

This study addresses a critical research gap by analyzing the core components, impacts, drivers, and implementation challenges of Industry 4.0. The fourth industrial revolution integrates advanced technologies like IoT, cloud computing, and cyber-physical systems into smart factories. This paradigm shift is transforming business processes across automotive, logistics, and energy sectors through the strategic integration of information and communication technologies (Oztemel & Gusev, 2020). The competences or components of Industry 4.0 bring significant advantages to organizations, including product customization, real-time data analysis, increased visibility, autonomous monitoring and control, vibrant product design and development, enhanced productivity, and greater attractiveness.

The key characteristics of Industry 4.0 are teamwork and incorporation of schemes, both horizontal and vertical. In vertical integration, Information and Communication Technology (ICT) is integrated into various levels of the organization, from floor-level control to production, operations, and management levels (Kiel et al., 2017). Vertical and horizontal integration use Industry 4.0 and ICT to synchronize production and data across companies. While integration is complex, it reduces costs and enhances productivity, efficiency, and customization. These technological advancements drive progress but also introduce societal challenges by fundamentally transforming product design, operations, and services (Gopal & Thakkar, 2016).

Industry 4.0 employs several advanced tools and technologies, thereby redefining conventional industrial processes. Industry 4.0 has a huge potential effect in many zones, and its request will have an impact across the entire value chain, improving production and engineering processes, improving product and service quality, optimizing customer organization relationships, bringing new business opportunities and economic benefits, changing educational necessities, and altering the current work environment (Götz & Jankowska, 2020). Digitization and interconnection of industrial processes (Industry 4.0) offer potential across all three dimensions of sustainability.

6.9. Overseeing the Contribution at a High Level

Supervisory-level management plays a central role in translating organizational plans into day-to-day operational actions. Supervisors ensure that instructions and directives formulated by top and middle-level management are clearly communicated and effectively implemented by

employees. In this context, control refers to the process of ensuring alignment between planned objectives and actual performance. Supervisors achieve control through continuous monitoring of work activities, step-by-step performance checks, and immediate corrective actions when deviations from planned tasks are identified. This ongoing supervision enables timely guidance and reinforces adherence to organizational standards, thereby maintaining effective operational control over subordinate activities (Arden et al., 2021).

In addition to monitoring and control, supervisors provide direct feedback to employees, contribute to performance appraisal processes, and communicate operational issues and employee concerns to higher management levels. Upper management, in contrast, focuses on defining the organization's mission, strategic direction, policies, and performance objectives (Shahin et al., 2020). Major organizational decisions—such as strategic planning, inter-organizational partnerships, branding, and public relations—remain the responsibility of top-level management, while supervisory management ensures that these strategic intentions are consistently executed at the operational level.

6.10. Automated System Virtualization

In Industry 4.0, virtualization will encompass several technological trends, including cloud computing, mobile technologies, and the Internet of Things (IoT). The ubiquity and scalability of cloud computing allow manufacturing to break free from the limits of its infrastructure and operate from any location (Kozlov et al., 2019). In practice, a computer in Louisiana could make decisions about a production plan in China, and vice versa. Building an efficient IoT system means creating a robust, high-availability network that provides employees, machines, computers, and applications access to data from any device. For this to be successful, virtual applications become a vital cog in this process. Always being connected, available, and capable of working on any device ensures the system can collect and process data from any platform and location, resulting in a more cohesive, communicative IoT system (Hoyer et al., 2020). There are some measures to improve warehouse management, as follows:

i. *Maximize and Optimize All Available Space:*

Rather than expanding your warehouse's footprint, consider better use of vertical space. Adding taller storage units and the right equipment to pick and store material can help you keep more in the same square footage, rather than adding expansion costs (Poma et al., 2020). In addition, consider the types and varieties of shelving used. Storing small items on pallet racks wastes space and makes them easy to misplace.

ii. *Lean Inventory:*

Adopting lean inventory practices in your warehouse is just as important as manufacturing. The basic premise of learning is only what you need, and nothing more. Possibly reduce or eliminate safety stocks and try to get suppliers to deliver smaller quantities more frequently.

iii. *Adopt Enabling Technology:*

A warehouse management system (WMS) or an ERP system with a strong WMS module can improve productivity by providing the most efficient routes and procedures for picking or putting away. In addition, the system delivers automated pick lists that can be sent to mobile readers, along with strategies to help eliminate mistakes and reduce wasted time and paper.

iv. *Organize Workstations:*

Organizing workstations to improve productivity because workers do not have to search for tools or equipment. Use the “5S” method from lean manufacturing to ensure your workstations are as organized as possible.

v. Optimize Labor Efficiency:

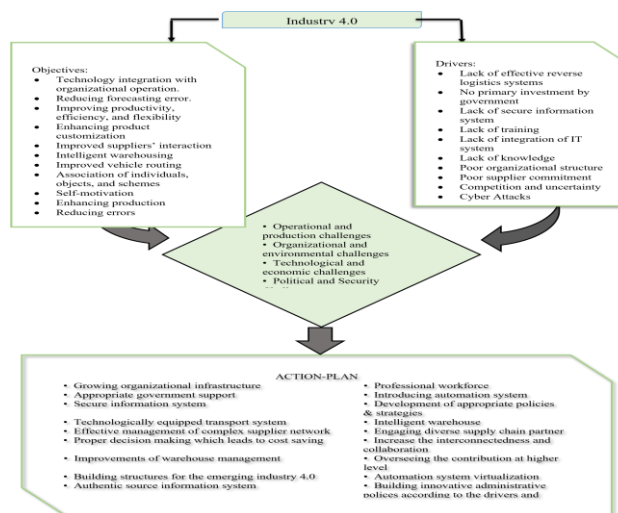
If your Warehouse Management System (WMS) lacks efficient picking plans, create them manually. Store high-volume, frequently bought-together items near the front and close together to minimize travel. Warehouse optimization aims to maximize the efficient use of space, time, and resources, often through automation to streamline operational processes (Kumar et al., 2020). Automation enhances warehouse management by reducing errors, increasing operational flexibility, and accelerating accurate data collection (Khaled & Alena, 2021).

7. THEORETICAL FRAMEWORK

Guided by the TOE framework and drawing on the empirical findings of this study, we propose a conceptual model to understand and navigate I4.0 implementation in the emerging pharmaceutical supply chain economy. This model illustrates the dynamic relationships between key constructs derived from our analysis. The process begins with External & Internal Drivers (e.g., competitive pressure, regulatory demands, efficiency goals), which motivate the pursuit of I4.0 technologies, represented as Implementation Objectives (e.g., real-time visibility, intelligent warehousing, predictive analytics). The successful application of these coordinated interventions aims to achieve the desired outcomes: enhanced supply chain agility, improved compliance, cost efficiency, and sustainable competitive advantage.

This conceptual framework contributes by integrating the generic Technology–Organization–Environment (TOE) structure with the context-specific, cyclical pattern of implementation barriers identified in this study. It offers a parsimonious visual tool that enables managers to identify dominant constraint points and supports researchers in formulating testable relationships for future empirical investigation (*see Figure 8: Theoretical Framework*).

Figure 8.
Theoretical Framework



Note. Author's Contribution.

8. CONCLUSION

This study set out to explore the specific challenges of implementing Industry 4.0 within Pakistan's pharmaceutical supply chains and to formulate a responsive action plan. By applying the Technology-Organization-Environment (TOE) framework to a rich qualitative dataset, the research provides nuanced insights that extend the existing literature.

The primary theoretical contribution lies in revealing the context-specific hierarchy and interdependence of barriers. While the findings align with the broad relevance of technological, organizational, and environmental challenges, they indicate that in emerging economies with volatile institutional settings, environmental constraints (e.g., regulatory uncertainty) and deep-seated organizational resistance can create a negative lock-in state, potentially impeding technological investment. This refines the TOE framework by showing that its context may not be equally weighted and can interact to create disabling conditions. Furthermore, the study provides nuanced insight into organizational resistance by highlighting the paradox of experienced personnel—valuable human assets who may simultaneously act as critical change blockers—thereby linking I4.0 adoption to socio-technical transition theory.

On a practical level, the study offers a context-sensitive intervention framework. It moves beyond generic barrier lists to provide a structured approach that explicitly addresses the identified lock-in. For managers, this suggests prioritizing sophisticated change management and phased pilot projects alongside technology adoption. For policymakers, it highlights the importance of providing clear strategic roadmaps and financial incentives to reduce investment risk. Collectively, these insights offer a coherent pathway for stakeholders to collaboratively address adoption challenges in similar organizational contexts.

In sum, this research illuminates local patterns and challenges in adoption of I4.0 while demonstrating how global frameworks can be interpreted and applied in a specific context. It provides a foundation for future studies, including potential quantitative validation or comparative research across sectors, without claiming generalization beyond the studied setting.

9. LIMITATIONS

While this study provides in-depth insights into I4.0 implementation challenges, its limitations must be acknowledged. Methodologically, the qualitative, interview-based approach, while essential for depth, primarily captures managerial perspectives. This may introduce a top-down bias, potentially underestimating the technical or frontline operational hurdles perceived by engineers and warehouse staff. Furthermore, the cross-sectional design offers a snapshot in time; the rapid evolution of both technology and Pakistan's regulatory landscape means the salience of specific barriers may shift, limiting the longitudinal applicability of the findings.

In this context, the focus on four large, established pharmaceutical firms means the findings are most transferable to similar organizations. Small and medium-sized enterprises (SMEs), which may face more acute resource constraints and less formalized processes, could encounter a different set of challenges not fully captured here. Finally, the study is deeply embedded in Pakistan's specific institutional environment, characterized by foreign exchange volatility, energy supply instability, and a developing digital infrastructure ecosystem. These powerful contextual variables fundamentally shaped the reported challenges (e.g., prioritizing cost over cutting-edge innovation). Consequently, while the theoretical framework (TOE) is portable, the specific ranking of barriers and the proposed action plan may require significant adaptation for application in other

national or industrial contexts with different institutional maturity. Future research should employ longitudinal designs, incorporate multi-tiered participant sampling, and conduct comparative cross-country analyses to validate and extend these contextually rich findings.

10. FUTURE RESEARCH

This study primarily focused on operational inefficiencies in pharmaceutical firms arising from limited technological adoption. Future research could extend this focus by examining and managing organizational inefficiencies at a more holistic level. As this study employed a qualitative research design, further quantitative investigation may be required to generate additional insights into Industry 4.0–related challenges. Such an approach would allow testing construct validity by empirically examining issues identified through interviews and observations. This, in turn, would enable organizations to better identify the factors contributing to Industry 4.0 inefficiencies and support managerial decision-making. From a theoretical perspective, the findings also highlight opportunities for future research to develop and validate innovative strategies to enhance industrial performance.

11. RESEARCH IMPLICATIONS

The findings of this study provide clear, actionable implications for supply chain managers and policymakers in the pharmaceutical sector, particularly in emerging economies. By addressing both current and emerging challenges, the study highlights practical strategies to improve pharmaceutical supply chain management. Supply chain managers should prioritize change management over technology acquisition, as cultural resistance often outweighs technical barriers. Formal change programs should actively engage experienced employees early on, clearly articulate the rationale for digital transformation, and align incentives with technology adoption.

Managers should further adopt a phased, ROI-driven investment approach, avoiding large-scale implementations in favor of pilot projects that deliver rapid, measurable benefits. High-impact initiatives, such as IoT-enabled cold-chain monitoring for high-value products, can demonstrate compliance and cost efficiencies, thereby strengthening organizational support for subsequent investments. The formation of cross-functional digital task forces that integrate supply chain, operations, quality assurance, and IT functions is essential to ensure operational feasibility and regulatory compliance, including GMP and data integrity requirements.

For policymakers, developing a stable Pharma 4.0 roadmap is critical, incorporating GMP-aligned implementation guidelines and data standardization frameworks to reduce uncertainty and guide private-sector investment. Financial barriers should be addressed through targeted subsidies, tax incentives, and low-interest financing, particularly for SMEs adopting foundational Industry 4.0 technologies. In parallel, industry–academia partnerships should be strengthened to address skills shortages through certified training in supply chain analytics, IoT maintenance, and industrial cybersecurity.

Finally, sustained investment in pharmaceutical research and development enhances population health while generating medium-term cost savings and operational efficiencies. Research also enables organizations to identify strategic strengths and weaknesses, supporting informed decision-making. The study underscores the importance of organizational strategy and culture in Industry 4.0 adoption, noting that while dedicated digital units can facilitate implementation, the

effective use of intangible digital capabilities and employee engagement remains central to long-term success.

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