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OPTIMIZING SUPPLY CHAIN PERFORMANCE THROUGH INDUSTRY 4.0: THE ROLE OF AUTOMATION AND KNOWLEDGE MANAGEMENT

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Abstract

The research aims at exploring readiness of textile industry of Pakistan for Industry 4.0 with focus on the mediating role of automation level (AL) and knowledge management level (KML) in the development of digital transformation. Building upon systems theory and the resource-based view, we introduce a conceptual model to assess the effects of these two constructs on supply chain performance (SCP) and the intention to adopt Industry 4.0 (PUOI). The managers of textile industries were surveyed, and data were collected and analyzed with SEM and CFA. This study suggests that automation, as well as knowledge management, can contribute to the potential usage level of Industry 4.0, while the roles of automation are more significant. Knowledge management is positively associated with supply chain performance, although automation and PUOI have weaker dependences at this lower level of adoption. The study contributes to theory by clarifying the interdependent roles of automation and knowledge management in digital readiness, while offering practical guidance for managers and policymakers. It cautions against assuming that automation alone ensures performance improvements and underscores the need for synchronized strategies that balance technology, human capital, and organizational processes. The framework provides actionable insights for strengthening Industry 4.0 readiness, competitiveness, and sustainability in emerging economies.

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Keywords: Automation Level, Knowledge Management Level, Supply Chain Performance, Industry 4.0, Readiness Level

Introduction

The significance of the textile industry in the Pakistan's economy is emphasized as it is the largest manufacturing sector in the country (Aneja et al., 2019). Being an export-oriented industry, brings foreign exchange and also creates a large number of employs due to its labor-intensive structure (Ali et al., 2021). It starts with the growing of cotton locally and then follows multiple phases.

There could be a growth opportunity in modernization and diversification. Improvement of the equipment, implementation of new technologies, and maintaining the sustainability could result in efficiency enhancement, quality improvement, and environmental damage decrease. Furthermore, searching for new markets, investing in the skills of workers, could help promote a long-term growth (Capestro & Kinkel, 2020).

The textile industry, despite its significance, is confronted with a multitude of obstacles such as energy shortages, frequent power interruptions, escalating production expenditures, outdated infrastructure, and inefficient equipment. Moreover, intricate tax legislation, intense overseas competition, and environmental apprehensions regarding resource utilization and pollution further compound the challenges (Bettiol et al., 2022).

The textile supply chain encompasses the complete process, from procuring fibers like cotton, wool, or synthetic materials, to spinning, weaving, dyeing, and finally finishing the fabric. Nonetheless, the global textile supply chain encounters noteworthy hurdles in logistics, quality assurance, and compliance with global standards (Cong & Gao, 2010).

Information Technology (IT) harbors substantial promise for enhancing business practices, education, technology, and economic advancement. By addressing local and national requirements, IT also has the potential to play a pivotal role in alleviating poverty in developing nations.

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The modern global economy heavily relies on IT and telecommunications infrastructure, which serve as vital frameworks for both national and worldwide advancements. Nonetheless, a digital divide persists in the access to information and communication technology between developed and developing nations (Macharia & Gituru, 2006).

I4.0 merges physical production with smart digital technology, improving efficiency, enabling flexible manufacturing, and introducing new products. I4.0 is marked by increased connectivity, automation, machine learning, and real-time data. This shift in thinking connects the physical, digital, and biological worlds, creating a more integrated approach to industry (Gafni, 2009).

Industry players and the government agencies have to balance the pros and the cons of I4. 0, carefully for secure future. The onset of I4. 0 has some controversies in how to accept it, which includes training specialists, investment in terms of upgrading application like hardware, job losses. A recent work of Oliveira Neto et al. (2024) underline these challenges and their direct effect on sustainability. Increased operational conditions could lead to the efficient and competitive production of good quality products in the textile sector in Pakistan with the help of the technological advancements. it is about automating all possible manufacturing process and reducing human as much as possible. AL: The quantity of work, typically done by humans, that may be carried out without human intervention. Automation is a way to improve manufacturing efficiency and lower cost by maintaining standard consistent quality of textile to the utmost benefit of all section of the textiles industry. It is these developments that are of paramount importance if we are not to be left behind (Chatchawanchanchanakij et al., 2023; Rajput & Singh, 2019).

Research Problem and Research Gap

The textile sector in Pakistan have a number of problems and two among them are automation and knowledge management which are indispensable in the nature of fast change and global competition in the present era. The

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drawbacks of the use of the conventional equipment and manufacturing techniques are high-cost and inefficiency. The absence of maturity in the adoption of Industry 4.0 technologies has limited this sector from expansion and compete overseas (Debnath & Islam, 2017).

Supply Chain Automation is vital for maximizing production, reducing lead times, and enhancing product quality. Despite the advantages, there is limited incentive for textile companies in Pakistan to make investment in technologies that remain elusive to market uncertainties and are not fully aware of its long-term positive consequences (Atzori et al., 2010; Gloy et al., 2013). Management Knowledge management is also one of the tools, which helps abolish this resistance, by giving the human resources the anatomy of the new systems and how they would be able to flex the systems to suite their needs while the enterprise also remains modern to match to the dynamic of the industry changes (Küsters et al., 2017).

The use of modern technology is also an issue in the energy sector since if the systems are not upgraded and are not combined with new technological advancements it compounds the challenges that face the industry such as flickering prices, energy-shortage crises and global trade difficulties(Jianguo & Solangi, 2023). The investment in automation and Industry 4.0 provides an opportunity to the industry to lower costs, improve efficiency and become more sustainable to regain its competitiveness in the global market (Stock & Seliger, 2016).

I4.0 technologies and their integration is crucial for enhancing the operational efficiency of the Pakistan textile industry's supply chain and addressing the competitive pressures in the global market. However there is limited amount of research on certain important aspects such as readiness to adopt and their immediate effect on changes of supply chain behavior. Although the advantages of automation on the performance of the industry at the global scale are reported but the emphasis on the contingent outcomes of these technologies and their adaptation within the Pakistani context is missing.Chatchawanchanchanakij et al. (2023) reported a study that focuses on the positive global impact and does not take into account the specific infrastructure and investment problems in PK companies, which are necessary to understand and improve the performance of supply chain in this market.

Another overlooked dimension is the role of implementation of the I4.0 technologies and effective knowledge management in the textile companies operating in Pakistan. There is a void to understand how these mechanisms get triggered within Pakistan and how industry 4.0 affects the knowledge management practices as global studies mention that industry 4.0 may leverage the knowledge management practices. Kumar et al. (2022) further stressed the necessity for more targeted research in this context in order to cope more closely with the particular challenges of the textile firms of the country.

Significance of Study

This study is crucial to revolutionize the Pakistani textile industry and adopt Industry 4.0 technologies. It seeks to evaluate the current state of the industry, areas that need improvement, and the industry's readiness to embrace technology. The results will facilitate the development of new technologies, improve efficiency and address global competition. Furthermore, the findings in relation to how Industry 4.0 can enhance the right supply chain performance, and contribute to the economic growth on the one hand and sustainability, on the other hand, will be a key input for policy-makers. This study will benefit the clothing industry as well as its relevant domains in terms of literature and application.

Literature Review

Automation Level

Industry 4.0 sets the stage for the digital factory, where automation—ranging from intelligent robotics to cloud-enabled control, streamlines operations and reduces the need for human involvement(Lasi et al., 2014; Wong & Kee, 2022).

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Automation of the supply chain, from sensor-based inventory systems that alert before stockouts to predictive systems that minimize waste, provides strategic flexibility and enhances customer-focused service delivery (Chowdhury & A Raut, 2019; Chowdhury et al., 2022).

Recent studies further reinforce this perspective: Industry 4.0 technologies, particularly integration and improved real-time visibility, boost supply chain performance by enhancing connectivity across partners (Reaidy et al., 2024). Going beyond performance, these technologies contribute to making supply chains more resilient and sustainable, utilizing tools like control towers, digital twins, or AI-assisted visibility systems to anticipate disruptions (Ghobakhloo et al., 2025; Jain et al., 2024).

Moreover, Industry 4.0 enables autonomous cooperation among machines. Smart factories, equipped with AI and cyber-physical systems, are increasingly capable of self-managing operations with minimal human intervention (Bassi, 2017; Gligor, 2014). Today's frameworks are far more sophisticated: robots learn, cloud and edge systems foster adaptability, and digital twins dynamically reflect supply networks (Li et al., 2024).

Despite these advances, implementation is not instantaneous. Factors such as firm size, product complexity, and internal integration influence the degree to which automation benefits a company—some firms experience greater advantages than others (Kim, 2022; Weeks et al., 2022). Digital adoption also presents its own set of challenges: sustainability concerns, data overload, security risks, and more complex decision-making regarding the prioritization of technologies (Alshdaifat et al., 2024; Birkel & Müller, 2025; Bobák et al., 2013; Setyadi et al., 2025)

H1a: Automation Level positively influences the potential use of Industry 4.0 in SC

H2b: Automation level is directly associated with SC performance

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Knowledge Management Level

Industry 4.0 adoption is not limited to technological upgrades; its success largely depends on skilled human capital and robust knowledge management (KM) systems (Manesh et al., 2020; Shee et al., 2018). Workforce readiness requires continuous reskilling and digital literacy development, as technological change redefines job roles and creates risks of displacement alongside new opportunities (Li et al., 2024). Recent studies emphasize that employee preparedness—supported by KM, IT competence, and soft skills—is central to Industry 4.0 transformation(Caroline et al., 2025; Hermawan et al., 2021).

Knowledge remains the most critical organizational asset, requiring cultivation, storage, and effective use (Nonaka, 1994). Within supply chains, knowledge sharing strengthens buyer–supplier collaboration, market intelligence, and innovation, improving overall performance(Zsidisin & Henke, 2019). However, ambiguity in KM practices and insufficient distinction between tacit and explicit knowledge may hinder these benefits (Schoenherr et al., 2014). When effectively managed, KM enhances decision-making, operational efficiency, and risk management (Ali & Gurd, 2020) and gains further value when integrated with analytics and sustainability strategies (Alam et al., 2023; Yang et al., 2023).

Csizmadia et al. (2023) show that Industry 4.0 tools promote collaboration and knowledge sharing in SMEs, though knowledge storage is less emphasized. A 2024 study on digitally transforming supply chains confirms that Industry 4.0 platforms improve visibility, transparency, and decision-making (Jain et al., 2024). Similarly, Li et al. (2024) highlight data governance as a critical enabler of KM in Industry 4.0 supply chains, linking human, technical, and regulatory factors.

Knowledge management also interacts with emerging technologies. (Aghaei et al., 2025) argue that Large Language Models (LLMs), when integrated with IoT and blockchain, can enhance supply chain responsiveness, provided KM frameworks support their responsible use. Educational innovations also play a role: Mixed-Reality learning environments foster engagement and skill development for Industry 4.0 contexts (Bondin & Zammit, 2025). Readiness models developed by (Ansari et al., 2025) systemize dimensions such as strategy, infrastructure, workforce skills, and cybersecurity, offering organizations structured pathways to I4.0 maturity.

Taken together, the literature underscores that Industry 4.0 is a socio-technical transformation. Its effectiveness depends on aligning advanced digital technologies with workforce development, robust KM practices, and strong governance frameworks.

H2a: KML positively impacts Industry 4.0 in supply chains.

H2b: KML is positively associated with SC performance.

Supply Chain Performance and Potential use of Industry 4.0

The concepts of readiness and maturity are related but distinct. Readiness refers to an organization's preparedness, including resources, skills, and attitudes, before initiating transformation, while maturity reflects the degree of progress achieved after implementation (Mittal et al., 2018; Shee et al., 2018). Maturity models (MMs) provide step-by-step pathways for organizational improvement(De Carolis et al., 2017), whereas readiness assessments evaluate the capability to begin that journey (Schumacher et al., 2016).

Evaluating maturity and I4.0 readiness is essential because many companies seek to transform their operations digitally without a clear idea of what it takes or what paths to take in order to do so (Ustundag et al., 2018). IT readiness is the extent to which digital technologies are exploitable (Dyerson et al., 2016) maturity reflects the level of integration that has been built over time (Kohlegger et al., 2009).

Research confirms that I4. 0 technologies of IoT, cloud computing and big data analytics can enhance supply chain efficiency, visibility and resilience to a great extent, if they are assessed and adopted systematically (Al Shuweihi

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et al., 2023; Fatorachian & Kazemi, 2021). Recent research emphasise the effects of disruption, especially in crisis situation that ultimately shaped the supply chain through resilience strategies and digital tools (Cherian & Arun, 2022; Marinagi et al., 2023).

New literature indicates that digital technologies also support new business models, such as PSS with AI and embedded sensors (Weking et al., 2019), supplier relationship with blockchain-driven transparency (Culot et al., 2019) logistics with IoT and forecasting in real time (Skapinyecz et al., 2018). They facilitate trust, cooperation and responsiveness of the global supply networks (Frank et al., 2019; Mourtzis et al., 2019).

In addition, advanced analytics and cognitive AI methods like machine-learning and natural language processing are transforming demand forecasting, decision making, and customization (Ghobakhloo, 2018; Oztemel & Gursev, 2020). Further studies report an increase in accuracy, coordination, and efficiency when incorporating Industry 4.0 across procurement, production, and logistics (Miragliotta et al., 2018; Tortorella, Prashar, et al., 2023).

However, challenges remain. Developing country firms encounter impediments ranging from lack of clarity surrounding the I4 definition. 0 and lack of information (Luthra & Mangla, 2018). Cybersecurity vulnerabilities as well as technological unemployment are further challenges to be addressed (Haddud et al., 2017). Nevertheless, the systematic measures of readiness and maturity allow the organizations to insert the digital technologies properly, thus leading to sustainable performance and competitive advantage (Ansari et al., 2025; Thneibat et al., 2023)

H3: High potential use of I4 in Sc impact positively on SC performance

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Conceptual Framework

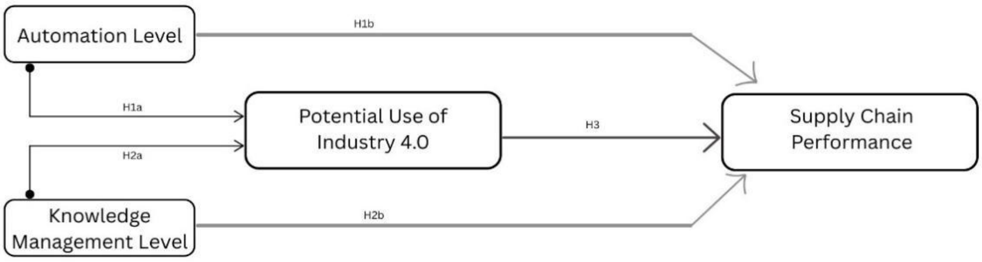

Figure 1: Conceptual Framework

Systems Theory

According to systems theory, organizations and supply chains are systems within which individual processes (subsystems) combine to produce system performance (Grant et al., 1994; Lawrence & Lorsch, 1967). Through this lens, efficient communication, knowledge sharing and collaboration amongst internal and external members are critical in making an organization competitive (Eslami et al., 2021; Oehmen et al., 2009). The theory emphasizes "that the performance of a supply chain is contingent upon how the subsystems are aligned, and integrated and that cause and effect exists with subsystems—changes in one subsystem may impact the other subsystems" (Alter, 2008; Fatorachian & Kazemi, 2021).

Evidence indicates that the I4.0 applications, such as IoT, big data, digital platforms, can facilitate the integration between suppliers, manufacturers, and customers, enhancing the agility and the resilience of the SC (Ghadge et al., 2020; Marinagi et al., 2023). Crucial to this is the management of knowledge that facilitates the swift transfer of information and decisions thereby facilitating adoption of automation and digital tools (Blome et al., 2014; Wiengarten & Longoni, 2015). Additionally, environmentally sustainable supply chain initiatives by I4.0 help in the promotion of environmental and economic performances corresponding to the holistic nature of systems theory (Bag et al., 2021; Umar et al., 2022). Hence, systems theory serves as a basis for understanding the role that KM

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and automation jointly play in I4. 0 readiness to increase supply chain efficiency and effectiveness.

Resource-Based View (RBV)

Resources-based view augments systems theory to emphasize firm specific resources and capabilities as sources of competitive advantage (Luthra & Mangla, 2018). In this light, knowledge and automation constitute strategic tools by which firms can exploit I4. 0 technologies. Companies with best-in-class knowledge management practices and greater levels of automation maturity are more likely to capture I4. 0 advantages, which cause cost reduction, quality enhancement, and customer satisfaction improvement (Kazancoglu et al., 2021; Mirando et al., 2021).

Digital technology add on sustainability outcomes by minimizing resource utilization and waste (Umar et al., 2022). Empirical evidence shows that I4. 0 has a positive impact on SCP, while KM and automation mediate this relationship (Erboz et al., 2022). The RBV also implies that it is the magnitude of I4. 0 relies on how prepared the firm is starting in order to activate resources such as knowledge retention, skills and technological infrastructure (Frederico et al., 2020).

Systems theory and RBV elucidate that KM and automation facilitate the optimal deployment of Industry 4.0 in supply chains. On the one hand, systems theory underscores the interconnectedness and information flows between supply chain partners; on the other, RBV recognizes that firm-specific knowledge and automation capacities are resources that mediate how technological readiness is translated into performance improvements (Eslami et al., 2021; Tortorella, Prashar, et al., 2023).

Methodology

The textile sector encounters challenges such as the choice of suitable distribution channels (Khan et al., 2023), inadequate government backing regarding tax benefits for exports, infrastructure enhancement, and a deficiency in technological progress(Afzal et al., 2017). Current framework

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assesses the industry's readiness for Industry 4.0 by appraising its knowledge management and automation capabilities. Through six progressive and cumulative metrics (Lucato et al., 2019; Pacchini et al., 2019) aligned with the ISO/IEC 15504-5 standard, we gauge organizational readiness.

The proposed framework offers a systematic method for evaluating Industry 4.0 readiness, helping companies identify areas needing improvement to better position themselves for future advancements. By comparing ideal conditions with the current state, organizations can implement strategies to enhance their readiness.

We recommend adopting Lucato et al. (2019) methodology, which calculates readiness by determining the ratio of points obtained in an evaluation to the maximum possible points for each element:
gn= (Points obtained from evaluating components of element e)/(Maximum possible points)

This methodology adapts the SAE J4000 and J4001 standards (Table 1) to assess how well the textile industry has integrated Industry 4.0 technologies, shifting from lean operational practices to a digital manufacturing environment. Applied to Pakistan's textile sector, it evaluates adoption and readiness, providing insights into areas for improvement and guiding the industry's digital transformation.

Table 1: ***Industry 4.0 Readiness***

Readiness Level (%)	Stage	Explanation
0 – 10	Conceptual	Industry experts possess a basic awareness of a few key technologies but lack in-depth understanding.
10-25	Initial	The sector is acquainted with some technologies but does not yet cover all emerging innovations.

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25 – 50	Basic	The industry is aware of all relevant technologies, although not all have been integrated into operations.
50 – 75	Progressive	Full knowledge of available technologies is established, with partial implementation underway.
75 – 90	Advanced	A significant portion of technologies is widely adopted and integrated across the industry, showing a strong understanding and usage.
90 – 100	Fully Developed	The industry has completely implemented the necessary technologies, reflecting a high rate of acceptance and integration.

In the second phase of the study, we utilized the Analysis of Moment Structures (AMOS) software. AMOS facilitates the application of statistical methods like Structural Equation Modeling (SEM) and Confirmatory Factor Analysis (CFA). SEM is employed for structural modeling, whereas CFA functions as the measurement model. SEM is used to depict hypothesized causal relationships among various constructs with statistical interdependencies (Douma & Shipley, 2023). The SEM analysis was carried out using AMOS version 24. AMOS was chosen for its user-friendly graphical representation of path diagrams. The suitability of the data with the proposed model was confirmed through SEM techniques. 370 responses were gathered for this analysis. Although there is no universally agreed-upon sample size, Jackson (2001) suggests a range between 200 and 400. Data for this research were obtained through a survey questionnaire distributed to operational managers, supply chain management (SCM) professionals, and managers in the textile industry, all actively involved in technology driven industry.

An assessment was conducted within Pakistan's textile industry to gauge its level of preparedness for Industry 4.0 and the ensuing effects on supply chain

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(SC) efficiency. The analysis primarily targeted textile enterprises registered with the Securities and Exchange Commission of Pakistan (SECP). Survey participants were drawn from various hierarchical levels, encompassing staff, middle management, and senior executives, as they possess extensive insights and hands-on experience within their respective organizations. Questionnaires were disseminated electronically via email, supplemented by select responses obtained through telephone interviews.

Item Selection

Automation Level

The automation level refers to the degree of automation in a system, ranging from no automation to full automation. Classification of automation levels indicates the extent of automation in relation to the entire system's function (Wessel & Gorlach, 2008). Automation spans from manual to fully automated systems, enhancing manufacturing efficiency, reducing production times, improving product quality, and optimizing supply chain communication (Dahmani, 2024). In internal supply chains, automation aids in developing responsive decision support systems, leading to faster, more efficient processes with improved quality (Coito et al., 2021). Moreover, automation and digital technologies help supply chains manage disruptions, as seen during the COVID-19 pandemic when Industry 4.0 technologies ensured resilience (Chatterjee et al., 2021). The human factors perspective on automation highlights intermediate levels between manual and fully automated systems, with each level requiring real-time control and varying cognitive and psychomotor tasks (Widzyk-Capehart & Zabłocki, 2020). Automation levels are measured according to Barua et al. (2004).

Knowledge Management Level

The proficiency in knowledge management concerns an individual, a group, or an organization's capacity to effectively supervise and utilize knowledge to achieve desired goals. Muhammed et al. (2011) introduce a framework linking these performance metrics on an individual level. To effectively manage

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organizational knowledge, it is essential for organizations to adopt a holistic approach, enhance strategic planning, and harmonize business processes with knowledge management (Cong & Gao, 2010). The correlation between knowledge management capabilities and organizational performance is critical for improving competitiveness. The knowledge management metrics utilized in this study are derived from Kearns and Sabherwal (2006).

Supply chain Performance

Supply chain performance involves assessing how effectively and efficiently the entire supply chain network achieves its objectives. The evaluation includes analyzing the activities of all participants in the supply chain, like suppliers, manufacturers, distributors, and retailers. Various metrics, such as cost, quality, delivery times, customer satisfaction, and flexibility, can gauge the success of the supply chain. The definition and specific metrics for evaluating supply chain performance can vary based on the industry or specific context. For instance, in the food industry, factors like traceability, food safety, and sustainability are critical for assessing supply chain performance, while in the automobile industry, metrics like inventory turnover, distribution efficiency, and effective management of fixed assets are more relevant (Tripathi & Talukder, 2023). These performance measurement indicators are sourced from (Singhry, 2015).

Analysis

The demographic profile of participants reveals diverse work experience, management levels, gender, and age distributions. Regarding work experience, the majority of participants (39%) had between 15–20 years of experience, followed closely by 35% with 10–15 years. About 15.4% had 16–20 years of experience, while only 10.5% had less than 5 years. In terms of management level, most respondents (63.2%) were staff line supervisors, 27.9% belonged to middle management, and 8.8% were part of top management. Gender distribution showed that males dominated the sample, representing 77.8%, while females accounted for 22.2%. With respect to age, one-third of

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participants (33.9%) were above 40 years, 32.8% fell in the 31–35 age group, 22.8% were between 36–40 years, and smaller proportions were found in the younger categories, with 6.8% aged 26–30 and only 3.7% under 25.

The evaluation of adoption level can be appraised utilizing a framework established by Lucato et al. (2019) for gauging a company's preparedness for empowering technologies. In accordance with the approach delineated by (Günther et al., 2017), the preparedness degree of a particular component, represented as 'n,' is computed by dividing the cumulative points acquired from the assessment by the highest achievable points.

gn = ∑Score obtained as a result of an evaluation of indicators of construct/ Maximum score possible (1)

DR = g1 + g2 + g3 + · · · +gn/ n = ∑n 1 gm/ n (2)

Here: DR = degree of readiness of a given company.

g1 = degree of adoption component 1 (first indicator).

g2 = degree of adoption component 2 (second indicator).

and gn = degree of adoption component n (nth indicator)

To achieve this, the scores of all received indicators were aggregated and then divided by the sum of the maximum attainable scores. The resulting numerical value indicates the potential for utilizing I4.0. This value was also converted into a percentage format, as shown in Table 2, for clarity and ease of understanding.

Table 2: ***KM and AL Adoption Level***

Dimensions	**Potential**
Advance	
KM	78.39
Intermediate	
AL	64.61

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The analysis revealed that knowledge management is progressing to advanced levels, while the Automation Level remains within the intermediate range, as indicated in the table.

Survey data are analyzed using the Statistical Package for the Social Sciences (SPSS) version 14, a widely utilized software for advanced statistical analysis (Zikmund et al., 2003). The software supports data filtering and preliminary computations, including frequencies, means, and standard deviations, which provide an overview of the dataset.

Structural Equation Modeling (SEM) assesses the relationships among variables. SEM, as a robust multivariate statistical technique, evaluates interactions between independent and dependent variables, whether continuous or categorical (Tabachnick & Fidell, 2001). Its methodological soundness and extensive adoption in academic research are well established (Bentler & Bonett, 1980; Bollen, 1989; Schumacker, 2002).

AMOS-24 (Arbuckle, 2005) facilitates the estimation of statistical relationships among constructs, their indicators, and dependent variables. The software generates causal path diagrams, enabling examination of hypothesized correlations and model specifications. The empirical model is compared with the hypothesized model to evaluate fit, with modifications applied when theoretically justified.

Given that the hypotheses are grounded in established literature, confirmatory factor analysis (CFA) is preferred over exploratory factor analysis (EFA) (Anderson & Gerbing, 1982; Hair et al., 1995). CFA employs the maximum likelihood estimation method (Anderson & Gerbing, 1988). The final stage incorporates causal relationships among constructs within the structural model, yielding a validated framework for hypothesis testing and interpretation.

CFA is conducted to validate the measurement model and test the hypothesized relationships between the latent constructs: Knowledge

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Management (KM), Automation Level (AL), Potential Use of Industry 4.0 (PUOI), and Supply Chain Performance (SCP), as shown in Figure 1.

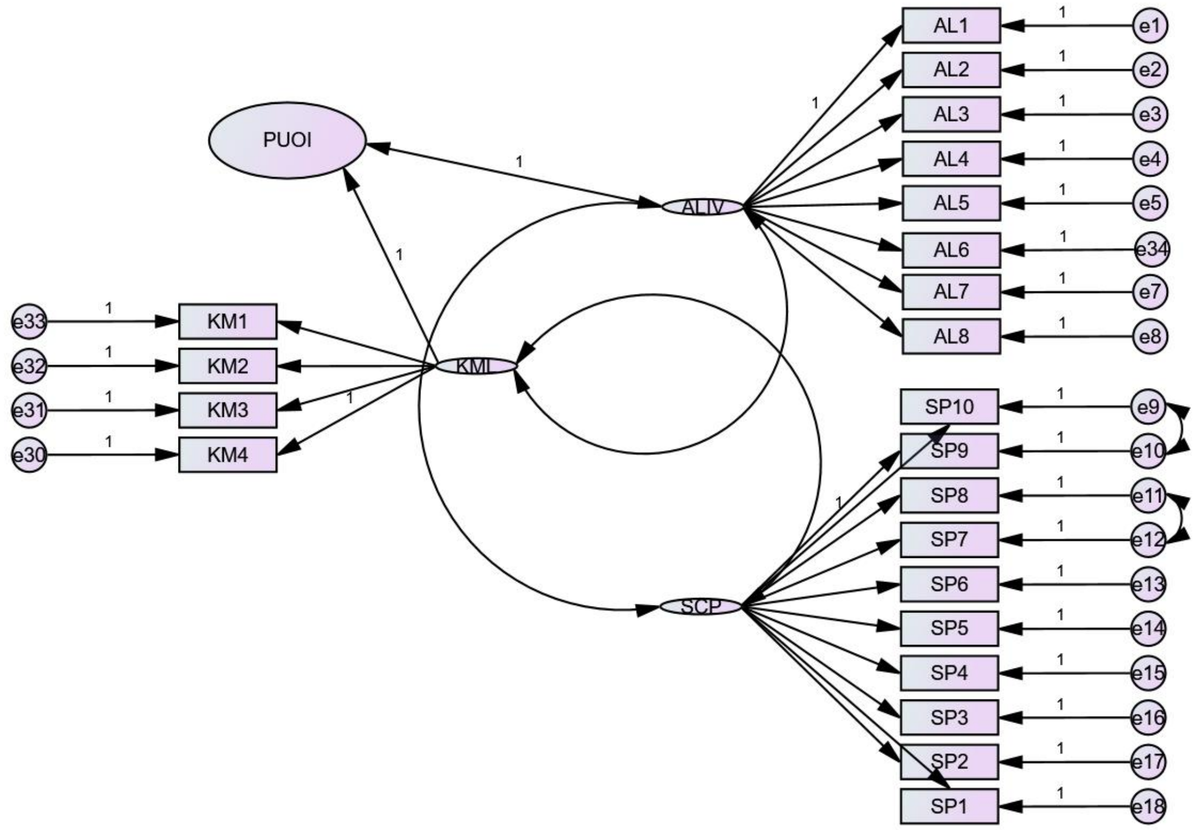

Figure 2: CFA Model

The **Model Validity Measures** table provides crucial metrics to assess the validity of the constructs in the measurement model. Based on the presented values, the validity of the model can be justified as follows:

Model Validity Measures

Validity Analysis

	CR	AVE	MSV	MaxR(H)	ALIV	KML	PUOI	SCP
ALIV	0.936	0.653	0.044	0.959	**0.808**			
KML	0.905	0.705	0.013	0.915	-0.065	**0.840**		
SCP	0.874	0.512	0.027	0.879	-0.164**	0.113	***	**0.642**

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Composite Reliability (CR): All constructs (ALIV = 0.936, KML = 0.905, SCP = 0.874) exceed the acceptable threshold of 0.70, indicating strong internal consistency and reliability of the measurement model.

Average Variance Extracted (AVE): AVE values for ALIV (0.653) and KML (0.705) are above the 0.50 threshold, demonstrating that these constructs explain a sufficient amount of variance in their indicators. SCP (0.512), though slightly lower, still meets the threshold, indicating acceptable construct validity.

Maximum Shared Variance (MSV): The low MSV values (ALIV = 0.044, KML = 0.013, SCP = 0.027) suggest that the constructs are distinct and do not share excessive variance, supporting discriminant validity.

Maximum R-Squared (MaxR(H)): ALIV (0.959) and KML (0.915) explain a large proportion of variance, indicating a strong model fit and relevance. SCP (0.879) also shows adequate explanatory power, reinforcing the model's fit to the data.

Inter-Construct Correlations: The correlations between the constructs (ALIV and KML = 0.808, KML and SCP = 0.642) are substantial, showing a strong relationship between these variables. The negative correlation between ALIV and SCP (-0.164) suggests a more complex interaction but does not undermine validity.

The **validity measures** justify the model's validity. The high CR and AVE values, low MSV, good MaxR(H), and reasonable inter-construct correlations indicate that the model is reliable, valid, and provides a solid foundation for testing the theoretical relationships among Knowledge Management, Automation Level, Potential Use of Industry 4.0, and Supply Chain Performance. The model shows good construct and discriminant validity, making it appropriate for further analysis. The threshold and vales and model fit values of variable under study are mentioned in Table 3.

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Table 3: ***Threshold and Model Fit Values***

Constructs	Acceptable Range	Model Fit
CMIN/df	< 5	1.9
GFI	≥ 0.8	.906
CFI	≥ 0.9	.960
TLI	≥ 0.9	.954
RMSEA	≤ 0.08	.051

The chi-square test assesses the alignment between calculated covariance matrices and observed data, with smaller values indicating better fit. A value approaching zero signifies a perfect match, while a higher value suggests greater discrepancy. In our model, the CMIN/df value was 1.9, indicating a good fit. The Comparative Fit Index (CFI) value of 0.960 and the Tucker-Lewis Index (TLI) value of 0.954 also reflect a good fit, as both exceed the recommended threshold of 0.90(Hu & Bentler, 1999; Tucker & Lewis, 1973). The Goodness of Fit Index (GFI) was 0.906, indicating an acceptable fit (Doll et al., 1994) The RMSEA value of 0.051 suggests a good fit for the model across the entire population (Browne & Cudeck, 1992). These results collectively demonstrate that the model fits the empirical data well.

Structural Equational Model (SEM)

Table 4: ***Hypothesis Results***

Hypothesis	P-values	Beta values
KML → PUI	0.000	0.352
ALIV → PUI	0.000	0.391
KML → SCP	0.034	0.145
ALIV → SCP	0.073	-0.113
PUI → SCP	0.087	-0.114

Results of Hypothesis is mentioned in Table 4. The positive moderate impact of KML on PUI is significant (Beta = 0.352, p-value =0.000). This suggests that with increasing KML, the increase of PUI is moderate. This means that

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KML is a significant predictor of PUI in the model. ALIV also has a significant positive effect on PUI (Beta = 0.391, p-value = 0.000). This indicates that ALIV is more positively associated with PUI than KML, refelcting that greater ALIV is significantly related to increased PUI. KML has apparently slightly positive (weak) relationship with SCP (Beta = 0.145, p-value = 0.034). That is, the higher KML values increase SCP slightly though their impact was weak. This suggests that KML affects SCP, but less strongly so than PUI. ALIV has a small but negative effect on SCP (Beta = -0.113, p-value = 0.073). Although this effect is not statistically significant at 5%, it provides weak evidence of a negative association between ALIV and SCP. With the rise of ALIV SCP slightly decreases, but in a very slight manner, so this relation must be considered carefully. PUI has a small negative effect on SCP (Beta = -0.114) but this effect is not statistically significant at 5% level (p-value = 0.087). While there is a weak negative relationship, there is not evidently strong enough to be considered statistically significant in this model.

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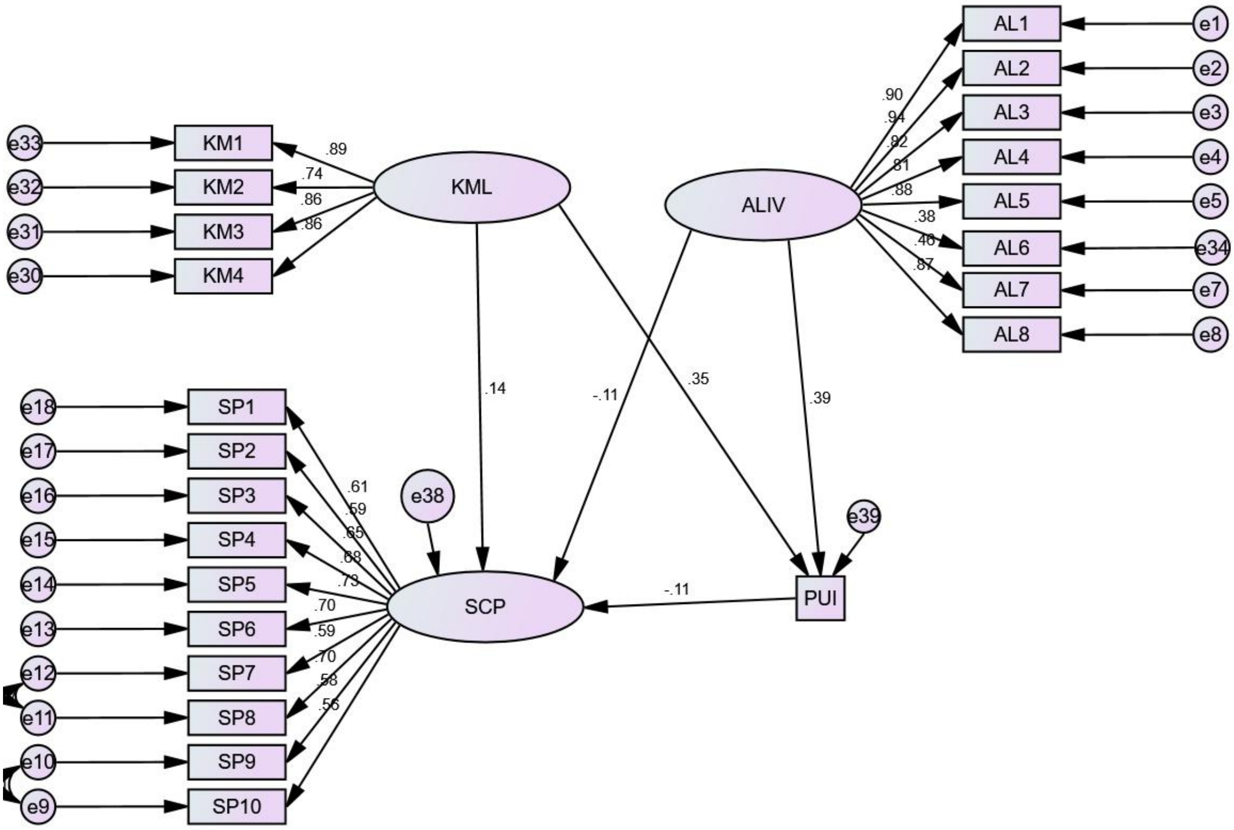

Figure 3: SEM Output

Figure 2 presents the path diagram illustrating the relationships among the variables: KML, ALIV, SCP, and PUI. This model includes latent variables (KML, ALIV, SCP, and PUI) and their respective observed indicators. The arrows represent both direct and indirect relationships among the constructs, with the numbers on the arrows representing the standardized path coefficients.

Discussion

Technological shifts, particularly those related to Industry 4.0, are often gradual processes where early adoption may not immediately result in significant impacts. The true effects of technology adoption might not be observable until certain maturity levels are reached." (Hermann et al., 2016).

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The impact of technology on organizational performance or processes often takes time to materialize, especially during early adoption phases, when organizations are still adjusting to new technologies and workflows (Kagermann & Wahlster, 2022)

During the early phases of Industry 4.0 adoption, businesses may not yet experience significant effects in areas like SCP or PUI because the systems and technologies being introduced are still being integrated and tested. The full impact may only emerge after the technology has been embedded into the organization's processes and operations.

"Early on in their integration of I4.0, businesses may not experience the 'right impact as soon as they would wish'. Work integration is not easy, and companies need to make changes to their processes, their people, and their culture before they are able to reap all the benefits of integrating systems." (Brettel et al., 2017). The effect of Industry 4.0 adoption on organizational performance may not be immediately significant due to the learning curve and the necessary infrastructural adjustments before the benefits can be fully realized (Vogel-Heuser & Bengler, 2023; Vogel-Heuser et al., 2021).

The shift towards Industry 4.0 is usually accompanied by complexity and uncertainty, mostly due to implementing new technologies into a running system. In this period of transition, businesses may experience difficulties, including lack of knowledge, lack of skills and lack of will, which may impede the (measurable) impact of adoptions of Industry 4.0 on, for instance, SCP and PUI**.**

"The introduction of advanced technologies such as automation, big data, and IoT in Industry 4.0 often causes disruptions, and organizations may not experience immediate improvements in performance as they adapt to these new systems and technologies."(Schwab, 2024).

Technological shifts like Industry 4.0 involve substantial changes to both organizational processes and technology infrastructure, making the transition period critical in understanding the lag between adoption and the realization of tangible effects. (Pereira & Romero, 2017; Pinheiro et al., 2019)

Knowledge Management Level (KML) and Potential Use of Industry 4.0 (PUI)

The result shows that KML has a statistically significant moderate direct positive effect on the PUI (Beta = 0.352, p-value = 0.000). This means that when KML increases PUI also increases slightly with moderate impact. These results are consistent with the those of (Tortorella, Prashar, et al., 2023), who concluded that good knowledge management (KM) practices, including creation, sharing and transfer of knowledge, are positively associated with the adoption of Industry 4.0 technologies. The study by (Deshmukh et al., 2024; Manesh et al., 2020) are consistent with this and stress that companies with an effective knowledge management scheme are more competent in dealing with the challenges associated with industry 4.0. These findings indicated that a higher presence of knowledge management allows the adoption of Industry 4.0 as well, supporting previous work that emphasizes the important link between knowledge management and innovation and technological utilization.

Automation Level (ALIV) and Potential Use of Industry 4.0 (PUI)

The research results show that there is a significant positive relationship between Poly factor Loading Automation Level ALIV and PUI (Beta= 0.391, p-value ≤0.013)) meaning that high levels of automation have a great deal of influence in the PUI towards the adoption of the 4th IR technologies. This observation is in accordance with that reported by Liu et al. (2020), say that automation in companies, when promoted, plays a significant role in increasing the adoption and good use of the technologies of industry 4.0. Automation technologies play a role in building the necessary foundation for the successful adoption of advanced technologies and thus the impact of ALIV on PUI in the current study is relatively higher. Queiroz et al. (2025) also validate this by mentioning that digitalization and automation are the major drivers to the implementation of Industry 4.0 and that automation is an

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essential requirement to the semantic model if supply chain should perform best and new technologies like the ones from I4.0 can be used.

Knowledge Management Level (KML) and Supply Chain Performance (SCP)

There is also a weak but significant positive effect of KML on SCP (Beta = 0.145, p-value = 0.034). The effect is not a strong one but indicates that increasing the level of knowledge management will very slightly help the supply chain to perform better. The result agrees with the result of Tortorella, Prashar, et al. (2023) posit that supply chain performance can be improved by using best knowledge management (KM) practices for improving information sharing, decision making, and innovation. The effect size may not be large, but this finding supports the proposition that knowledge management contributes to enhancing supply chain performance, which agrees with research works on importance of managing flow of information and resources efficiently in the operational activities of a supply chain.

Automation Level (ALIV) and Supply Chain Performance (SCP)

The research reports a weak and a negative impact of ALIV on SCP (Beta = -0.113, p-value = 0.073), but not significant at 5% level. This effect is weak but indicative of face-type (ALIV) and skull-type (SCP) being inversely related. This result is counterintuitive as automation is generally assumed to enhance supply chain performance. Nonetheless, it is consistent with the finer resolution proposed by (Fosso Wamba, 2012; Queiroz et al., 2025), who claim that the effect of automation on supply chain performance is both complex and contingent. "Automation needs to be considered in an intelligent manner: It should not be pushed just for the sake of adopting new technology; rather, it can be employed on small subproblems and studied how these improve performance”. This marginal negative relationship indicates that although automation can contribute to increased performance of the supply chain, the success of automation is related to some other factors, including readiness in the organization, integration of the technology, and alignment with operations.

Automation significantly impacts supply chain operations, enhancing accuracy and efficiency. However, challenges such as technology-related issues and employee resistance can hinder its positive effects, particularly in the context of Industry 4.0 (Qureshi et al.). Effective automation relies on internal synchronization, external coordination, and integration, but the growing complexity of global supply networks makes maintaining visibility and managing risk more difficult (Wichmann et al., 2020).

In the textile and garment industry, rapid adaptability is crucial due to short product lifespans and unpredictable demand (Bruce et al., 2004). However, automation can effect coordination in supply chains, leading to longer lead times and reduced efficiency (Shen et al., 2017). Properly implementing automation is essential to avoid negative impacts on supply chain performance.

Potential Use of Industry 4.0 (PUI) and Supply Chain Performance (SCP)

The analysis reveals a weak negative effect of PUI on supply chain performance (Beta = -0.114, p = 0.087), suggesting a slight negative correlation. This indicates that the increased use of Industry 4.0 technologies does not necessarily lead to improved supply chain performance. This finding aligns with the work of Fosso Wamba (2012)) and Queiroz et al. (2025), who argue that while Industry 4.0 adoption can enhance supply chain performance, its success depends on proper implementation and the alignment of technological integration with the firm's operations. The marginal negative impact in this study reinforces the idea that adopting I4.0 technologies alone does not guarantee improved supply chain performance and highlights the need for strategic management and effective integration.

These findings are in line with studies carried out in other emerging markets, like Latin America, especially where the initial I4. 0 adoption would lead to performance erosion through infrastructure and skills shortfalls (Bianchi et al., 2017). Key barriers to I4. 0 adoption rate of enabling

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technologies remains low, and this constrains the effective use and integration of data across the value chain. Successful I4. 0 deployment will depend on collective effort from supply chain partners and a mindset of continuous innovation. But resistance to change, inflexibility, can hinder that (Fatorachian & Kazemi, 2021).

Research also highlights that while I4.0 technologies can improve supply chain performance, the associated organizational changes can cause disruptions, negatively affecting performance in the early stages. Despite benefits such as increased sustainability and efficiency, the complexity of integrating these technologies can overwhelm these advantages, resulting in inefficiencies and delays (Akhtar, 2022).

In Pakistan's textile industry, which is still in the early stages of digital transformation, disruptions are particularly pronounced due to a lack of infrastructure, expertise, and readiness for advanced technologies (Ali & Gurd, 2020). Insufficient investment in I4.0 technologies and poor deployment within the supply chain further limit the potential benefits (Ali, 2021). Consequently, the lack of significant improvements in supply chain performance is not surprising and can be attributed to insufficient integration, collaboration, investment, and misalignment of evaluation criteria. To realize I4.0's full potential, organizations must overcome these barriers through strategic planning, improved collaboration, and targeted investments.

Theoretical Contribution

This research contributes to the Resource-Based View (RBV) and Systems Theory by distinguishing, yet intertwining, the influence of KM and automation to the potential adoption of Industry 4.0 and supply chain performance. They also echo the present view of knowledge as a strategic intangible resource that allows purchases to take advantage of external technological opportunities (Barney, 1991; Grant et al., 1994; Teece, 2007). Automation is a confirmed as a key sub-system, whereas results demonstrate that the effect of automation depends on the fit in the total organized whole

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(Bertalanffy, 1968). Connecting knowledge creation, sharing, and integration in terms of Industry 4.0 readiness, the results are consistent with previous research (Tortorella, Cauchick-Miguel, et al., 2023) while they advance RBV by highlighting how internal capabilities shape the impact of emerging technologies. The effects on supply chain performance suggest that the gain from technology adoption does not come automatically. Rather, the benefits are present when digital tools are embedded within and can inform complementary resources, in accordance with (Liu et al., 2020; Shao et al., 2021).

Practical Contribution

In addition, for practitioners, the study provides significant directional advice to managers seeking to steer digital transformation. Reinforcing the knowledge management appears to be essential to improve readiness and flexibility to embrace Industry 4.0 technologies. These firms develop strong knowledge-based processes such as knowledge creation, spreading, and combination, and so are extremely well-prepared to benefit from the automation and digital systems to achieve competitive advantage. At the same time, automation efforts need to be closely coordinated with enterprise plans, human resources, and the supply chain to avoid any potential inefficiencies. This warning not to adopt a higher is better argument becomes even more urgent when automation is further increased. Rather, it is necessary that enterprises consider Industry 4.0 as a holistic endeavour: one that involves the integration of technological, organizational and human resources. We offer several actionable implications for the firms looking to strike a right balance between innovation, resilience and sustainability within an evolving digitalized context of supply chains.

Limitations and Future Prospects

The study's focus on Pakistan's textile industry limits its applicability to other sectors and regions, restricting a broader understanding of Industry 4.0 (I4.0)

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impacts. the survey-based data collection method may HAVE biases, inaccuracies, and measurement errors.

The research emphasizes I4.0's potential rather than its actual implementation, overlooking individual stakeholder experiences. Research is needed to examine the adoption barriers within Pakistan's textile sector, highlighting success drivers and obstacles. Investigating the role of I4.0 in sustainability, including resource monitoring, waste reduction, and energy efficiency, will also support the adoption of greener practices in the industry. Organizations should enhance knowledge management and streamline supply chain processes before integrating I4.0. Effective change management, staff training, and the investment in appropriate technologies are critical for successful I4.0 adoption.

Additional studies should examine the social implications of I4.0 adoption, such as job displacement, skills development, and workforce training. Understanding generational differences in I4.0 perceptions, along with investigating work experience's impact, will provide further insights into the technology's societal acceptance. Lastly, comparative studies across industries in Pakistan will enhance cross-sector knowledge exchange and improve decision-making for I4.0 integration.

Conclusion

This research focuses on the roles of KM and automation in affecting 4IR and supply chain performance. By aligning knowledge resources, automation, and system integration, firms can pursue digital transformation that balances efficiency, resilience, and sustainability in an increasingly dynamic supply chain landscape. Theoretically, the results contribute to the Resource-Based Theory as they provide evidence for the strategic role of knowledge management in a technology context. They also contribute to Systems Theory by demonstrating that the automation is a key subsystem whose influence varies with its fit to upper-level organizational processes. Those insights confirm that the effects of digital transformation depend on the interplay

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between resources and systems and not limited to simply adopting technologies. Through the coordination of knowledge resources, automation and system integration, firms may transition to digital transformation that is efficient, resilient and sustainable in the context of a more volatile supply chain performance.

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