Textile 4.0 in Pakistan: Readiness Assessment, Barriers, and Strategic Recommendations

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ABSTRACT

This study examines the adoption of Industry 4.0 (I4.0) in Pakistan's textile sector, focusing on two key objectives: assessing the current readiness for I4.0 and identifying barriers to I4.0 implementation. We employed a mixed-methods approach, combining quantitative surveys (n = 106) and qualitative interviews conducted using an online Google Form. The research applies an adapted IMPULS readiness model to evaluate six dimensions of I4.0 readiness. As the first comprehensive readiness assessment of Pakistan's textile sector, this research supports RBV and STTT theories along with the direct contributions to SDG-9 (Industry, Innovation, and Infrastructure) by evaluating I4.0 readiness gaps, SDG-8 (Decent Work), through workforce skill interventions, SDG-4 (Education), Pakistan Vision-2025 and international trade compliance (e.g., GSP+) by proposing actionable strategies for policymakers and industry leaders to transition toward sustainable smart manufacturing. Findings reveal significant gaps across infrastructure, skills, and strategic vision, placing the sector at an Intermediate Level with an overall readiness score of 2.060. The study further identifies critical barriers impeding the transition to Industry 4.0, despite the textile sector's substantial contribution to Pakistan's economy. Actionable recommendations are proposed for policymakers and industry stakeholders to support the shift toward sustainable, smart manufacturing.

Keywords: Industry 4.0, Textile Sector, Digital Transformation, Readiness Assessment, Barriers

JEL Classification Codes: L67, O14, O33, Q55

1. INTRODUCTION

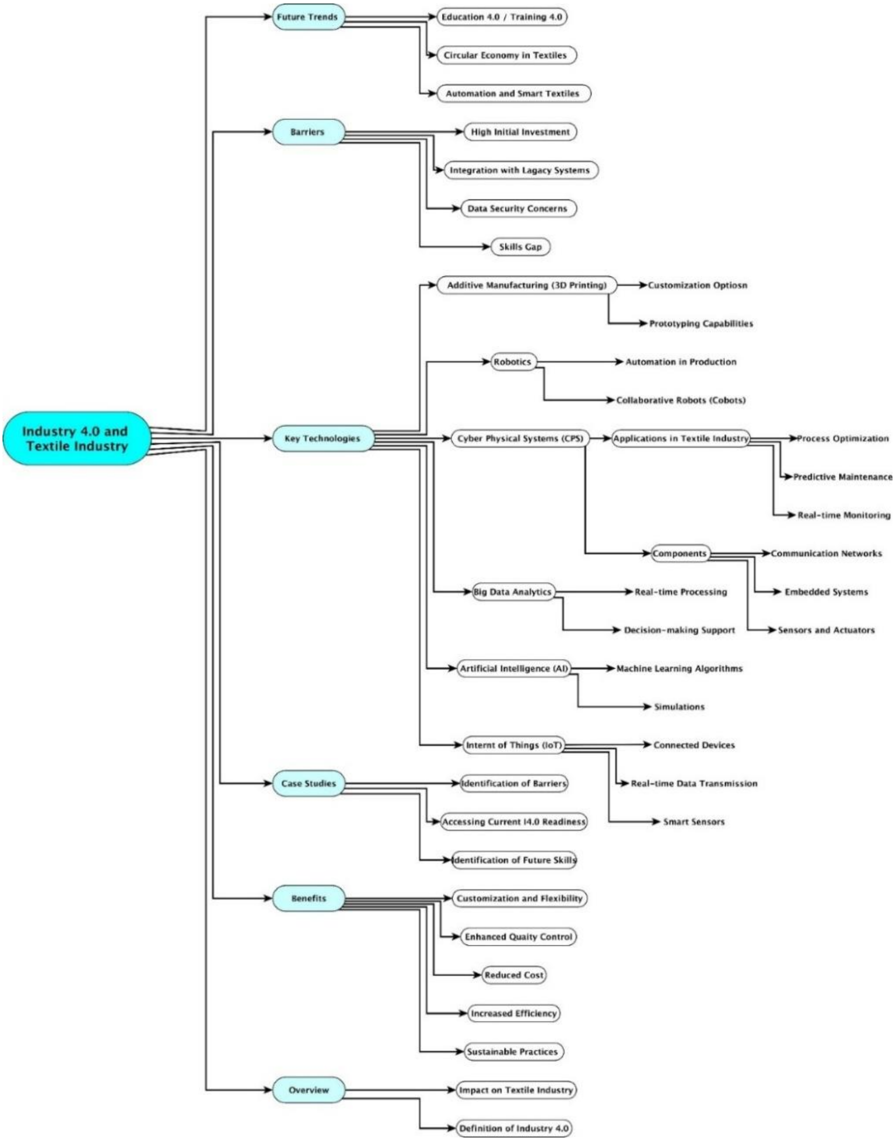
Industry 4.0 technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and Big Data Analytics are reshaping global manufacturing ecosystems (Lu, 2017; Sriram & Vinodh, 2021). The idea was first conceptualized as part of Germany's economic development strategy at the Hannover Messe in 2011 (Gershwin, 2018). The core premise of Industry 4.0 lies in its ability to enable real-time data collection, analysis, and utilization across all production levels, facilitating intelligent decision-making and operational optimization (Raj et al., 2020). Projections indicate that early adoption of digital transformation could boost manufacturers' productivity by 55% and profits by 15% globally (McKinsey & Company, 2016).

Pakistan's textile sector contributes 8.5% to GDP, accounts for 40% of industrial employment, and makes up 60% of total exports (Government of Pakistan, 2023). However, it stands at a critical crossroads in this digital revolution. The sector is facing mounting pressure to modernize its production capabilities as global textile manufacturing is shifting toward Asian economies, including Pakistan, under initiatives like the Generalized System of Preferences Plus (GSP+) agreement (Lasi et al., 2014). Despite its economic significance and alignment with Pakistan Vision 2025, the country's adoption of Industry 4.0 technologies lags behind global standards. This poses a competitive threat as regional rivals such as India (34% adoption) and Bangladesh (27% adoption) rapidly advance in digitalization (Raj et al., 2020; Khin & Kee, 2022).

Some large manufacturers in Pakistan's textile sector are adopting basic digital technologies, such as ERP systems and automated machinery; however, the overall implementation of Industry 4.0 shows significant disparities (Salman et al., 2023). This technological lag is particularly concerning given the sector's crucial role in Pakistan's economy and its potential for driving national industrial growth. The World Economic Forum (2020) reports that 84% of global businesses are advancing toward digitalization, with 50% actively reskilling their workforce for automated jobs (Schwab & Zahidi, 2020). Pakistan's textile industry faces challenges like high logistics costs, burdensome conventional processes, and low productivity (Government of Pakistan, 2023). Thus, strategic adoption of Industry 4.0 solutions could unlock a $6.7 billion annual productivity opportunity (McKinsey & Company, 2023).

The barriers to Industry 4.0 adoption in Pakistan's textile sector are multifaceted and deeply entrenched. Technological challenges include inadequate infrastructure for IoT implementation, with only 23% of Pakistani firms having adopted basic AI or Big Data solutions. Financial constraints pose another significant hurdle, as the high capital expenditure required for digital transformation often exceeds the capacity of small and medium textile enterprises (Mittal et al., 2018).

Figure 1: Industry 4.0 and Key Technologies in Textile Industry



Source: Author's Contribution.

Human resource limitations further compound these challenges, with studies indicating severe shortages of personnel skilled in emerging technologies (Gajdzik & Wolniak, 2022). This skills gap is particularly acute at operational levels, where floor-level workers often lack the basic digital literacy required for smart manufacturing environments (Shahzad et al., 2025). Figure 1 illustrates Industry 4.0 and its key technologies, which can contribute to increased efficiency, cost reduction, enhanced quality control, and sustainable practices, as well as potential barriers to adoption and other related issues.

1.1. Objectives of the Study

In this backdrop, this study addresses two critical research objectives to advance understanding of Industry 4.0 adoption in Pakistan’s textile sector. First, it seeks to comprehensively assess the current readiness level of textile firms for digital transformation through the adoption of the IMPULS readiness model (Moeuf et al., 2020). Second, the research aims to systematically identify and analyze the barriers hindering Industry 4.0 implementation. The findings will enable stakeholders and policymakers to develop more effective implementation roadmaps under Pakistan's Vision 2025, prioritize resource allocation, and ultimately enhance the global competitiveness of this vital national industry. The next section describes the literature review to provide more understanding of Industry 4.0 and assess the readiness.

1.2. Significance of Study

This study provides a comprehensive assessment of Industry 4.0 readiness in Pakistan's textile sector, a critical component of the national economy. It contributes to theoretical advancement by applying the Resource-Based View (RBV) and Socio-Technical Transition Theory (STTT) within the context of a developing country. The practical framework developed through this research can serve as a model for other manufacturing industries undergoing similar digital transformations. Key contributions include an industry-specific diagnostic toolkit, evidence-based policy recommendations, such as targeted subsidies and workforce upskilling, and a strong foundation for future empirical studies on digital transformation in emerging economies.

2. LITERATURE REVIEW

2.1. Bohn (1998) Industry 4.0 and Manufacturing Sectors

The concept of Industry 4.0 builds upon earlier industrial revolutions but distinguishes itself through the seamless fusion of digital and physical systems. Sriram and Vinodh (2021) defined it as the real-time, intelligent, and digital networking of people and equipment for managing business processes and value-creating networks. The industry 4.0 concept has fundamentally transformed global manufacturing paradigms through the integration of cyber-physical systems (CPS), the Internet of Things (IoT), and artificial intelligence (AI).

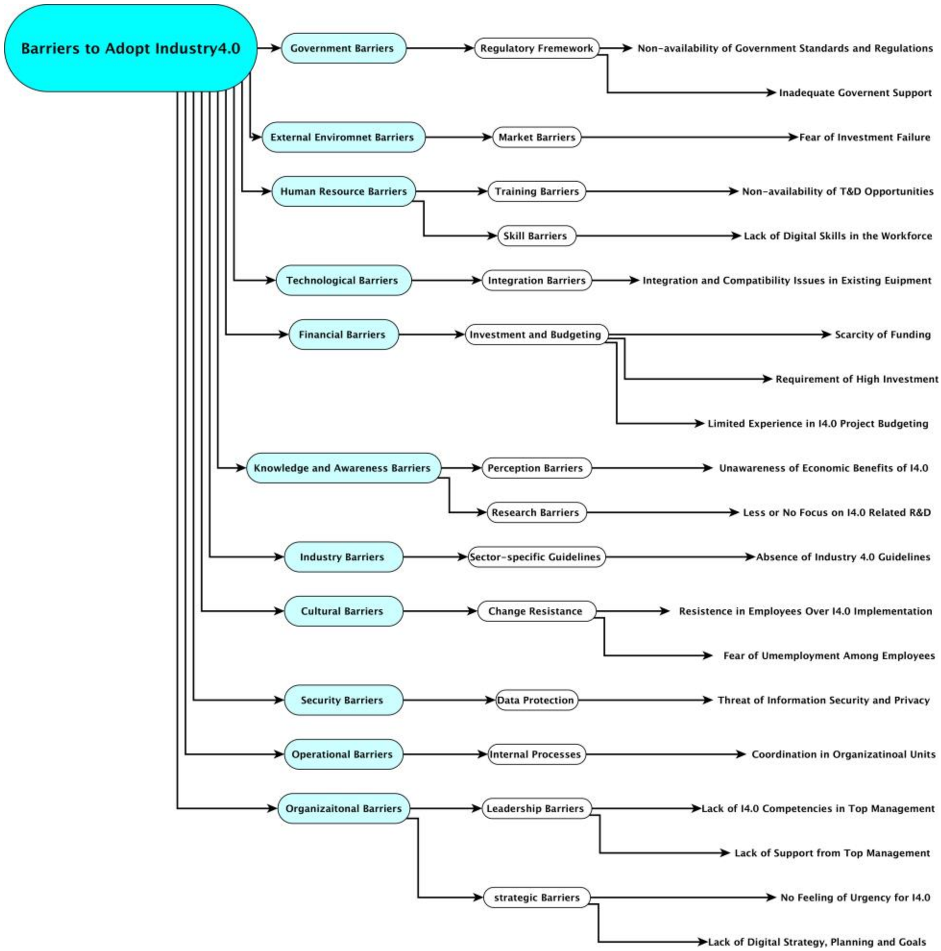
These digital technologies collectively enhance productivity by up to 55% and profitability by 15% (McKinsey, 2016; Raj et al., 2020). This paradigm shift represents smart, interconnected production systems capable of real-time data exchange and autonomous decision-making (Lu, 2017). However, the adoption of these technologies varies significantly across regions. For instance, Germany's Industrie 4.0 initiative and China's Made in China 2025 program have driven widespread implementation in manufacturing sectors (Zhou et al., 2015).

Industrialized nations have made significant strides in adopting digital technologies; however, developing economies like Pakistan still face unique challenges, particularly in key sectors such as textiles, which is a critical manufacturing sector contributing 8.5% to GDP and employing 40% of the industrial workforce (Government of Pakistan, 2023). However, this important sector lags due to infrastructural, financial, and cultural constraints (Mittal et al., 2018). A systematic analysis identified 24 key barriers, categorized into technological, financial, and human resource challenges. Financial constraints are particularly prohibitive, with 58% of firms citing high implementation costs as a primary obstacle (Wu et al., 2016). Figure 2 highlights various barriers to adopting Industry 4.0.

1.3. I4.0 and Assessing the Current Readiness

The concepts of readiness and maturity have gained significant attention in both academic and practical spheres (Kiel et al., 2017). Further, it is important to understand the distinction between readiness and maturity, as both are distinct concepts that form the foundation of our discussion about readiness. The Cambridge Dictionary defines readiness as willingness or a state of being prepared for something, while the Oxford Dictionary describes it as the state of being fully prepared for something (Stevenson, 2010). Maturity, on the other hand, is defined as a very advanced or developed form or state, fact, or period of being mature (Stevenson, 2010). Interestingly, the literature identifies many models and associated key characteristics often used to evaluate Industry 4.0 (I4.0) readiness. Schumacher et al. (2016) posits that most industrial organizations fail to adopt I4.0 due to insufficient knowledge or expertise in evaluating their digital readiness.

Figure 2: Potential Barriers to Adoption I4.0 in Textile Industry



Source: Author’s Contribution

The readiness of the textile sector to adopt Industry 4.0 varies significantly across regions and countries. In Bangladesh, for instance, the Ready-Made Garment (RMG) industry has been assessed using the IMPULS model, which revealed that most factories are at a low readiness level, rated no higher than level two on a six-level scale (Rahman et al., 2025) “IR 4.0 Readiness of Apparel Industry in Bangladesh,” 2022). Similarly, in Sri Lanka, the apparel industry was found to be at an intermediate level of readiness, with a score of 1.91 on a five-point scale

(Lakmali et al., 2020). In Pakistan, the textile industry's readiness was evaluated using the University of Warwick model, highlighting varying levels of preparedness among manufacturers (Ali, 2021). India, for instance, has made progress through its National Digital Skills Mission, achieving a 34% adoption rate, compared to Pakistan's 11% (Raj et al., 2020). Vietnam, meanwhile, has leveraged foreign direct investment (FDI) to establish technology parks, addressing infrastructural deficits (Khin & Kee, 2022). These comparisons underscore the need for tailored strategies in Pakistan, where simultaneous deficiencies across financial, technological, and human capital domains create a uniquely challenging environment. Table 1 presents the mapping of the research questions and objectives of this study.

Table 1: Mapping Research Questions and Research Objectives of Study

Research Questions (RQs)	Research Objectives (OBs)
RQ1: What is the overall and sector-wise current Industry 4.0 readiness of the textile industry of Pakistan?	OB1: To empirically assess the current overall and sector-wise I4.0 readiness of the textile industry of Pakistan
RQ2: What are the major barriers hindering the adoption of Industry 4.0 in Pakistan's textile industry?	OB2: To identify and analyze the barriers to adoption of Industry 4.0

Source: Author's Own Contribution

3. RESEARCH METHODOLOGY

3.1. Study Design

We adopted a mixed-methods design, integrating quantitative and qualitative approaches to comprehensively assess Industry 4.0 readiness and the barriers to its adoption in Pakistan's textile sector. Quantitative data were collected using an adapted VDMA-IMPULS model survey administered via Google Forms to experienced professionals across various textile units to assess current I4.0 readiness, while qualitative insights regarding adoption barriers were gathered through embedded open-ended questions and measured using a 5-point Likert scale within the same instrument. This design enabled parallel data collection, integration, and triangulation, ensuring a holistic understanding of readiness levels and contextual challenges.

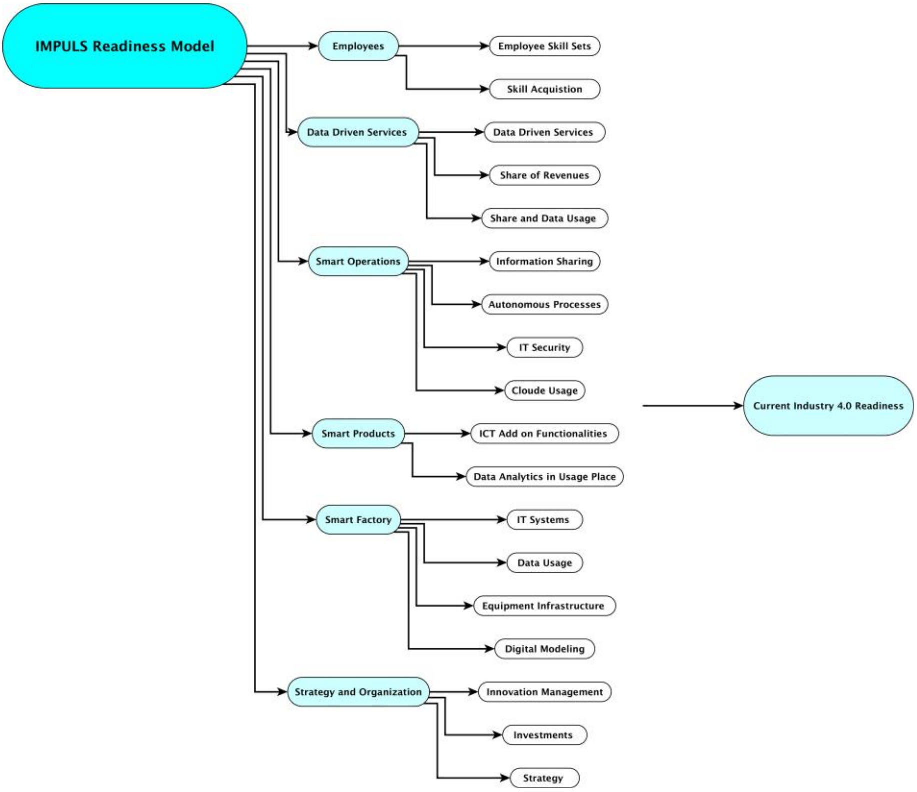
Assessing readiness for Industry 4.0 requires a structured framework, and the IMPULS model developed by Germany's VDMA has emerged as a leading tool in this regard. The IMPULS model has been widely recognized and adopted among scholars as a robust framework for evaluating Industry 4.0 readiness within manufacturing enterprises (Schumacher et al., 2016). It measures six core dimensions, strategy and organization, smart factory, smart operations, smart products, data-driven services, and employees, alongside 16 relevant sub-dimensions applicable to the manufacturing sector, including the textile industry (Sony & Naik, 2020; Rauch et al., 2020).

Figure 3 illustrates the original layout of the IMPULS model, while Figure 4 presents a flow diagram of the same model.

Figure 3: Original layout of IMPULS Readiness Model

Source: Lichtblau et al., 2015.

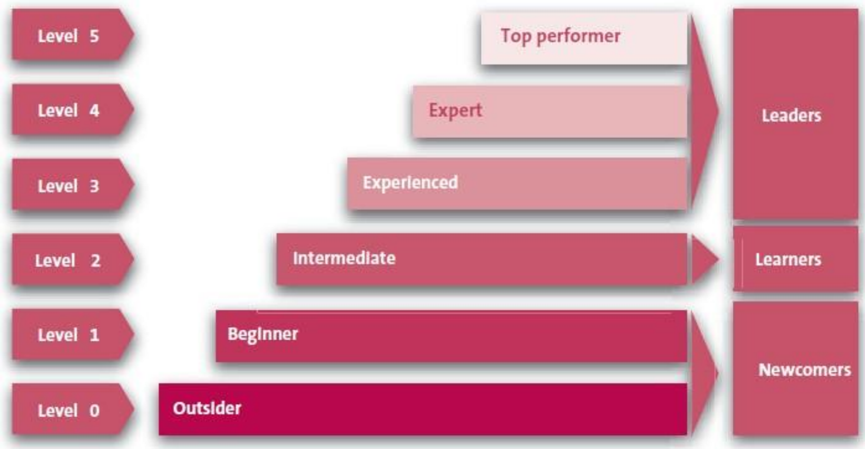
Figure 4: 6-Dimensional Flow Diagram of IMPULS Readiness Model



Source: Lichtblau et al., 2015

The resulting overall readiness score is measured on a scale from 0 to 5 and classifies the organization into three distinct categories: Newcomer, Learner, or Leader, as shown in Figure 5.

Figure 5: Level and Groups Readiness as per IMPULS Model



Source: Lichtblau et al., 2015

3.2. Sampling

A modified version of the VDMA-IMPULS survey was distributed online via Google Forms to textile automation experts, engineers, and technical managers with five or more years of experience. The respondents completed sections related to the six dimensions of Industry 4.0 (I4.0) readiness and the barriers to its adoption. Given the geographical dispersion of textile units across the country, a convenience sampling technique was employed to maximize participation from textile organizations. Data was collected using a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree). Participation was voluntary, and informed consent was obtained at the beginning of the survey. All responses were anonymized, and the data was stored securely to ensure confidentiality.

3.3. Data Collection

The data were collected from 106 textile organizations across five manufacturing types: Yarn Manufacturing (YM), Fabric Manufacturing (Weaving), Fabric Manufacturing (Knitting), Garments Manufacturing (GM), and Home Textiles. Garments Manufacturing recorded the highest response rate with 33 organizations, followed by Textile Processing with 22, and Yarn Manufacturing with 20.

Weaving and Knitting received 15 and 13 responses, respectively, while Home Textiles and Polyester Fiber production had minimal representation, with only 2 and 1 responses.

Geographically, Punjab dominated the sample with 81 responses, followed by Sindh with 24, and Khyber Pakhtunkhwa (KPK) with 1 response. Faisalabad contributed the highest number of city-level responses (45), followed by 30 from Lahore, 22 from Karachi, and a combined total of 9 from Multan, Kotri, and Gadoon.

Workforce data revealed that 95 responses came from organizations with 500 or more employees. Organizations with fewer than 500 employees were excluded from the study due to their limited impact on large-scale industrial transformation. This rich dataset provides valuable insights into the textile sector's manufacturing diversity and regional distribution, forming a strong basis for in-depth analysis. Furthermore, it illustrates that 89% of the responding textile organizations are substantial in workforce and size.

4. RESULTS AND DISCUSSIONS

4.1. Calculation of Readiness Score for the Textile Sector

This section presents a mathematical equation (Equation 1) to calculate the overall readiness score for the textile sector, specifically focusing on the following segments: Yarn Manufacturing, Fabric Manufacturing (Weaving), Fabric Manufacturing (Knitting), Textile Processing, and Garments Manufacturing.

Input Data

Let R = $\{r_1, r_2, \ldots\ldots\ldots\ldots r_{106}\}$ represent the readiness scores of the 106 units across the textile manufacturing sector.

Overall Readiness Score Calculation

The overall readiness score $\overline{X}$ is calculated using the mean:

$$\overline{X} = \frac{1}{N}\sum_{i=1}^{N} r_i$$

where

N = 106 (total number of units).

$\overline{X}$= Overall readiness score

r_i = Readiness score of the i-th unit

Table 2: Summary of the Industry wise current 14.0 Readiness and Overall Readiness of Textile Industry

Type of Industry	No. of Units	Readiness Score (Mean)	Readiness Level	Readiness Group
Yarn Manufacturing (YM)	21	2.205	Level 2	Intermediate Learner
Fabric Manufacturing (Weaving) (FM-W)	15	2.374	Level 2	Intermediate Learner
Fabric Manufacturing (Knitting) (FM-K)	13	2.165	Level 2	Intermediate Learner
Textile Processing (TP)	22	2.009	Level 2	Intermediate Learner
Garment Manufacturing (GM)	33	1.889	Level 2	Intermediate Learner
Home Textiles (HT)	2	0.908	Level 1	Beginner Learner
Overall Current 14.0 Readiness of the Textile Industry	106	**2.060**	**Level 2**	**Intermediate Learner**

Source: Author's Contribution

Table 2 presents the evaluation of Industry 4.0 (I4.0) readiness in Pakistan's textile sector, revealing substantial disparities in digital sophistication among 106 firms across five subsectors: Yarn Manufacturing, Fabric Manufacturing (Weaving), Textile Processing, Garment Manufacturing, and Home Textiles. Three key insights emerge from the analysis:

First, the sector's aggregated readiness score of 2.060 places it in the "Intermediate Learner" category according to the IMPULS model. However, this average mask significant internal variation, with individual firm scores ranging from 0.00 (Level 0 – Outsider) to 3.605 (Level 4 – Expert/Leader).

Second, a sub-sectoral breakdown illustrates nuanced readiness patterns. The Yarn Manufacturing segment (n = 21) achieved an average readiness score of 2.205, maintaining its classification within Level 2 (Intermediate Learner). Notably, several firms in this group demonstrated advanced readiness, with the highest score reaching 3.605, indicating leadership-level capabilities.

Third, the Fabric Manufacturing – Weaving segment (n = 15) achieved an even higher mean readiness score of 2.374, also within the Level 2 category. Of the 15 firms assessed, seven exhibited characteristics consistent with the "Leader" level, with a peak score of 3.494, suggesting strong digital integration in a subset of firms and reflecting this subsector’s competitive edge in I4.0 adoption.

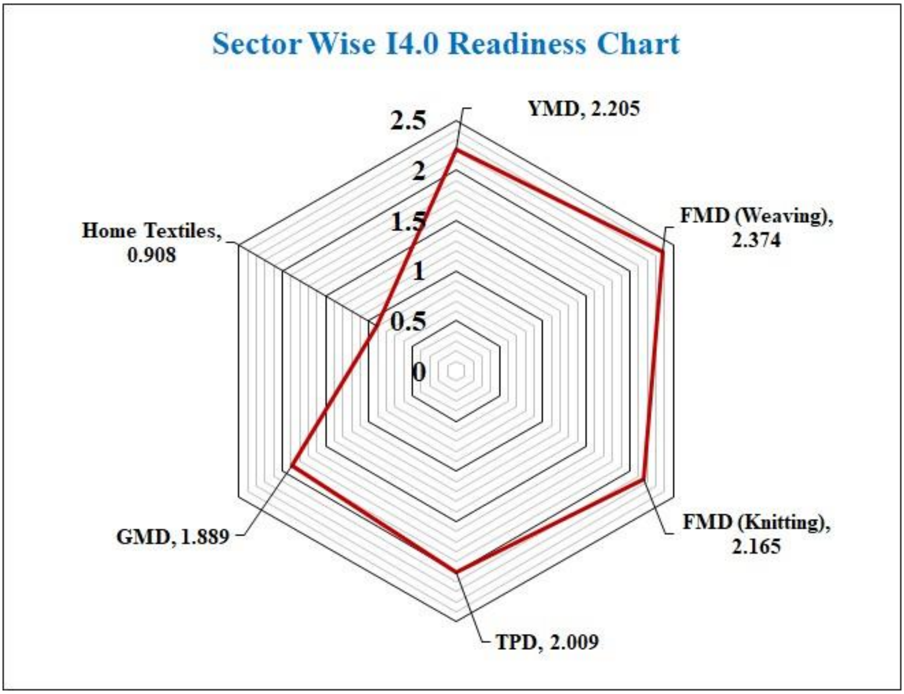
The Fabric Manufacturing – Knitting segment (n = 13) attained an overall Industry 4.0 readiness score of 2.165, placing it within the "Intermediate Learner" category. This score reflects substantial digital performance, particularly among firms classified as Experienced, with the highest individual score reaching 3.494. Similarly, the Textile Processing sector (n = 22) reported an overall readiness score of 2.009. Notably, eight firms in this category were classified within the Leader group, suggesting a strong concentration of digitally advanced units at the Experienced level.

In contrast, the Garments Manufacturing sector (n = 33) exhibited greater internal variability, with an average readiness score of 1.889. While 11 firms were identified at the Experienced level, a significant number (n = 22) were classified as Beginner, Intermediate, or Outsider. This dispersion indicates a critical need for targeted developmental initiatives to elevate the digital maturity of less advanced units within the sector.

Finally, the Home Textiles segment emerged as the lowest-performing group, with an overall readiness score of just 0.908. This underperformance is largely attributable to the limited sample size (n = 2), which restricts generalizability and calls for further investigation with broader sectoral representation.

For better understanding of the results, Figure 6 shows the results graphically through a radar chart representation of readiness scores across textile subsectors. The chart highlights three critical comparative insights.

Figure 6: Readiness Results of Textile Industry of Pakistan



Source: Author's Contribution

i. **Sectoral Leadership and Lagging Segments:** The plotted data confirms Fabric Manufacturing – Weaving as the most digitally prepared subsector (2.374), extending its lead over Yarn Manufacturing (2.205) by 7.7%, while Home Textiles (0.908) remains a pronounced outlier at 61% below the Weaving benchmark. This visualization aligns with empirical findings from the VDMA's global assessments, where weaving typically leads in automation due to higher process standardization (Lichtblau et al., 2015). The chart's asymmetrical geometry, with Home Textiles forming a sharp inward spike, mirrors the "core-periphery" digital divide observed in Pakistan's textile sector (Government of Pakistan, 2023).

ii. **Upstream vs. Downstream Readiness Gradient:** The radial progression from Yarn (2.205) to Fabric (Weaving: 2.374; Knitting: 2.165) to Textile Processing (2.009) and finally Garments (1.889) illustrates a consistent decline in readiness as production moves downstream. This pattern substantiates RBV theory's emphasis on resource allocation, where capital-intensive upstream sectors (YMD, FMD) invest more heavily in digital infrastructure than labor-intensive (GMD, Home Textiles) downstream units (Moderno et al., 2024). The gap between the highest (FMD–Weaving) and lowest (Home Textiles) scores exceeds comparable differentials in India and Bangladesh, underscoring Pakistan's acute polarization (Raj et al., 2020).

iii. **Threshold Analysis:** The chart's quadrant demarcations (implied by score ranges) reveal that only two subsectors—FMD–Weaving and YMD—cross the IMPULS Learner threshold (2.0+), while three (TPD, GMD, Home Textiles) fall below critical benchmarks for sustainable digital transformation (Maisiri & van Dyk, 2021). Notably, knitting (2.165) narrowly misses the Learner designation, suggesting this subsector may require targeted interventions to bridge the 0.165-point gap, a finding corroborated by case studies of knitting units in Faisalabad.

Table 3 presents the results of the literature review, identifying 24 critical barriers to Industry 4.0 adoption in Pakistan's textile sector, which can be grouped into four primary dimensions. Human capital challenges emerge as particularly significant, including acute shortages of digital skills (Bakhtari et al., 2021), workforce resistance due to concerns about job security (Norman, 2020), and deficiencies in leadership competencies for implementing the industry 4.0 strategy (Ajmera & Jain, 2019). Financial constraints present another major hurdle, characterized by high implementation costs (Buer et al., 2018), perceived investment risks (Kamble & Sharma, 2018), and insufficient research and development (R&D) funding (Rajnai & Kocsis, 2018). Technological limitations further complicate adoption, with challenges ranging from the incompatibility of legacy equipment (Da Xu et al., 2014) and inadequate IT infrastructure (Kamble & Sharma, 2018) to cybersecurity vulnerabilities (Kiel et al., 2017). Strategic and policy gaps complete the barrier ecosystem, manifested through the absence of digital roadmaps (Petrillo et al., 2018), a lack of government incentives (Bogoviz, 2019), and weak industry standards (Oesterreich & Teuteberg, 2016). This interconnected web of barriers demonstrates how financial and human capital constraints exacerbate technological and strategic limitations, with workforce-related challenges being particularly prominent and underscoring the critical need for “Training 4.0” initiatives to complement technological investments. The prevalence of these barriers underscores the complex and multifaceted nature of digital transformation in Pakistan’s textile sector, where addressing one dimension alone proves insufficient without concurrent progress in others.

Table 3: Barriers to Adoption I4.0 in Manufacturing Sector with References

Sr. No.	Identified barrier to I4.0	Reference
1.	Lack of digital/IT skills	(Bakhtariet al., 2021),
1.	Lack of Training & Development Opportunities	(Dalenogare et al., 2018),
2.	Employment disruptions for current employees/operators	(Raj et al., 2020)
3.	Resistance/Fear in Employees	(Norman, 2020)
4.	There is a lack of experience in the organizations regarding I4.0 project management and budgeting	(Rauch, et al., 2020),
5.	There is a lack of appropriate I4.0 related skills, competencies, and experience in leadership/top management	(Ajmera & Jain, 2019)
6.	Top management is not providing sufficient Support/Effective change management for the adoption of I4.0	(Dobrowolska & Knop, 2020),
7.	Requirement of High Investment	(Buer et al., 2018),
8.	There is scarcity of financial resources for adoption of I4.0	(Dalenogare et al., 2018),
9.	There is a risk of taking the initiative and resulting failure on investment for I4.0	(Kamble et al., 2018)
10.	It is difficult to change organization and its process for I4.0	(Raj et al., 2020)
11.	Upgrading existing machines and equipment for I4.0 is an issue	(Raj et al., 20200), (Da et al., 2014),
12.	Coordination across different units of an organization is challenging	(McKinsey, 2016),
13.	Inadequate Internet coverage and deficient IT infrastructure	(Kamble et al., 2018)
14.	There is lack of Knowledge Management	Kamble et al., 2018)

	Systems	
15.	Lack of established standards and common reference architecture	(Kamble et al., 2018)
16.	There is a risk of information security and privacy breaches if I4.0 is implemented.	(Kiel et al., 2017)
17.	The is lack of digital culture and I4.0 orientation	(Raj et al., 2020)
18.	There is a lack of industry-specific guidelines in organization about I4.0	(Agrawal et al., 2019)
19.	There is no digital strategy, planning, or goals for I4.0 so far	(Petrillo et al., 2018)
20.	lack of clear and well-defined articulation of the economic benefits of I4.0 of I4.0	(Agrawal et al., 2019)
21.	There is a lack of clear comprehension / understanding of IoT benefits	(Raj et al., 2020)
22.	There is less/no focus on R&D on I4.0 adoption	(Agrawal et al., 2019)
23.	Organizations don't see urgency to adopt I4.0	(Ivanov et al., 2019)
24.	There is a reluctance to adopt I4.0 as no Govt. Standards and regulations do not exist for the adoption of I4.0	(Oesterreich & Teuteberg, 2016)

Source: Author's Contribution

4.2. Analysis of Barriers to Adoption Industry 4.0

Besides assessing the current Industry 4.0 (I4.0) readiness, we analyzed 20 barriers to I4.0 adoption (four barriers were excluded from the study due to a mean value of less than 3.00, and two were removed due to similar or duplicate meanings). These barriers were measured on a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree) through responses from 106 textile industry professionals. The mean value was used to rank the barriers, and descriptive statistics (i.e., mean, standard deviation, and frequency distributions) were calculated for each barrier.

Table 4 presents the ranking of the barriers (from highest to lowest) based on their mean and standard deviation scores.

Table 4: Ranking of Barriers by Mean Importance (Highest to Lowest)

Rank	Barrier nature	Mean	SD	Strongly Agree %
1	Lack of Digital Skills in the Workforce	3.84	1.12	34.9%
2	Requirement of High Investment	3.72	1.31	32.6%
3	Fear of Unemployment among Employees	3.67	1.21	29.1%
4	Resistance in Employees over I4.0 Implementation	3.63	1.19	27.9%
5	Lack of Support from Top Management	3.58	1.24	25.6%
6	Lack of I4.0 Competencies in Top Management	3.55	1.18	23.3%
7	Fear of Investment Failure	3.52	1.35	22.1%
8	Scarcity of Funding	3.48	1.38	20.9%
9	Limited Experience in I4.0 Project Budgeting	3.45	1.15	18.6%
10	Integration & Compatibility Issues in Existing Equipment	3.41	1.32	17.4%
11	Coordination in Organizational Units	3.38	1.27	16.3%
12	Threat of Information Security and Privacy	3.34	1.41	15.1%
13	Absence of Industry-specific 4.0 guidelines	3.30	1.29	14.0%
14	Lack of Digital Strategy, Planning and Goals	3.27	1.25	12.8%
15	Non-availability of T&D Opportunities	3.23	1.33	11.6%
16	Unawareness about the Economic Benefits of I4.0	3.19	1.22	10.5%
17	No Feeling of Urgency for I4.0	3.15	1.28	9.3%
18	Less or No Focus on I4.0-related R&D	3.12	1.31	8.1%
19	Inadequate Government Support	3.09	1.36	7.0%
20	Non-availability of Government Standards and Regulations	3.05	1.30	5.8%

Source: Author’s Own Contribution

4.3. Key findings

The results revealed three barriers. Workforce-related challenges emerged as the most critical, as reported both in literature and by various researchers. These include a lack of digital skills in the workforce (M = 3.84, 95% CI [3.67–4.01]) and fear of unemployment (M = 3.67, CI [3.49–3.85]), which ranked the highest, with 34.9% and 29.1% of respondents strongly agreeing, respectively. Financial and managerial barriers followed, notably the requirement for high investment (M

= 3.72, CI [3.54–3.90]) and a lack of top management support (M = 3.58, CI [3.40–3.76]). Systemic/institutional barriers, such as the absence of government standards (M = 3.05, CI [2.87–3.23]), were also perceived as important.

This study critically evaluates the readiness of Pakistan's textile sector for Industry 4.0 (I4.0)—a transformation essential for maintaining the industry's global competitiveness amidst rising regional competition from India, China, Bangladesh, and Vietnam. As a cornerstone of Pakistan's economy, the sector contributes 8.5% to GDP, 60% to exports, and employs 40% of the industrial workforce. Thus, the textile sector's digital transition is both an economic imperative and a strategic opportunity. Grounded in the Resource-Based View (RBV) theory, the research reveals that the sector's current readiness is at an Intermediate Learner stage, with notable disparities across subsectors. Yarn Manufacturing (YM) and Fabric Manufacturing (FM) demonstrate higher readiness, particularly in Smart Operations and Smart Products, while Textile Processing (TP), Garment Manufacturing (GM), and Home Textiles lag—especially in Smart Factory integration and Data-driven Services. These gaps mirror the digital divide observed in other economies in the Global South and underscore the uneven distribution of tangible resources (e.g., IoT infrastructure) and intangible resources (e.g., workforce skills), aligning with RBV's emphasis on resource heterogeneity as a driver of competitive advantage.

The study presents the potential barriers, particularly in the context of Pakistan's Generalized Scheme of Preferences Plus (GSP+) trade status, granted by the EU, which requires adherence to sustainable production standards. Our findings reveal that addressing critical barriers, such as financial constraints (reported by 58% of firms), leadership resistance (identified by 67% of managers), and workforce skill gaps (with only 23% trained in IoT/AI), could simultaneously enhance both digital transformation and GSP+ compliance. The textile sector's current readiness level, which is at the Intermediate Learner stage (readiness score of 2.060), suggests the need for urgent interventions to meet evolving international standards while maintaining competitiveness.

Our study proposes that these barriers be addressed through a three-pronged approach aligned with Pakistan Vision 2025: (1) targeted subsidies for technology adoption to overcome financial hurdles, (2) executive training programs to combat leadership resistance, and (3) vocational partnerships with technical institutes to close skill gaps via Education 4.0 through learning factory concepts. This strategic remediation would not only accelerate Industry 4.0 adoption but also strengthen Pakistan's position in preferential trade agreements by demonstrating a commitment to sustainable, tech-driven manufacturing practices. The proposed measures directly support SDG 9 (Industry, Innovation, and Infrastructure) and

SDG 8 (Decent Work and Economic Growth) while creating a framework for other GSP+ beneficiary nations facing similar digital transformation challenges in both the textile and traditional manufacturing sectors.

5. POLICY RECOMMENDATIONS

Our study proposes that the identified barriers be addressed through coordinated efforts to meet the objectives of Pakistan Vision-2025:

- The implementation of targeted subsidies and soft loans through the Ministry of Commerce and the Small and Medium Enterprises Development Authority (SMEDA) to overcome financial hurdles for the textile industry.
- The launch of executive digital leadership development programs via the National Textile University and the National Business Education Accreditation Council (NBEAC) to combat leadership resistance and build strategic foresight.
- The establishment of vocational partnerships and Education 4.0 initiatives between NAVTTC (National Vocational & Technical Training Commission), TEVTA (Technical Education and Vocational Training Authority), and leading textile clusters to close smart skill gaps through learning factory models and simulation-based training.
- The Planning Commission of Pakistan, the Ministry of Education and Professional Training, and the Ministry of Industries and Production should integrate Industry 4.0 readiness into national textile policy frameworks to support long-term digital industrialization.

This strategic remediation would not only accelerate Industry 4.0 adoption but also strengthen Pakistan's position in preferential trade agreements by demonstrating a commitment to sustainable, tech-driven manufacturing practices. The proposed measures directly support SDG 9 (Industry, Innovation, and Infrastructure) and SDG 8 (Decent Work and Economic Growth) while creating a framework for other GSP+ beneficiary nations facing similar digital transformation challenges in both the textile and traditional manufacturing sectors.

6. RESEARCH IMPLICATIONS

The study's practical implications are profound. For industry leaders in Pakistan’s textile sector, the study provides a diagnostic toolkit to prioritize investments, e.g., upgrading Smart Factory capabilities in Garment Manufacturing, or enhancing data analytics in Textile Processing industries. Policymakers can leverage these insights to design subsidies for SMEs or align vocational training with I4.0 skill demands (SDGs 4 and 9). The study also highlights the urgency of addressing workforce anxieties through initiatives like Training 4.0 or Education 4.0 programs, which could boost morale and productivity (Farrukh Shahzad et al., 2025).

7. LIMITATIONS

Though the research provides critical insights into Industry 4.0 readiness in Pakistan's textile sector, several limitations must be acknowledged. First, the sample size of 106 textile firms, though statistically robust, may not fully capture the sector's diversity, as micro-enterprises and rural textile units were underrepresented. Second, the study's focus on major industrial hubs (e.g., Karachi, Lahore, Faisalabad) could overlook regional disparities in technological adoption. Third, reliance on self-reported data from the industry may introduce response bias, particularly regarding sensitive financial or technical challenges. Fourth, the rapid evolution of Industry 4.0 technologies means some findings may require periodic validation to remain relevant.

8. FUTURE WORK

Future studies should expand this work by incorporating small and medium-sized enterprises (SMEs) and home textile units to better represent sectoral diversity, while longitudinal analyses could track the evolution of readiness over time. Further comparative studies with regional peers, such as India, Bangladesh, and Vietnam, may help identify transferable best practices for effective digitalization. Studies may also be conducted to examine the digital integration of supply chains, encompassing both upstream suppliers and downstream logistics partners. By addressing these gaps, Pakistan's textile sector may maintain its competitiveness in the fast-evolving digital era.

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