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Research Article

Readiness Assessment and Adoption Barriers for Industry 4.0 Technologies in Indian SME Manufacturing: An Empirical Study Using AHP and Structural Equation Modelling

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Abstract

Industry 4.0 — encompassing the Internet of Things (IoT), Cyber-Physical Systems (CPS), Big Data analytics, cloud manufacturing, and additive manufacturing — represents a transformative paradigm for industrial production. While large enterprises in developed economies have made significant strides in I4.0 adoption, small and medium enterprises (SMEs) in emerging economies, particularly India, face distinctive structural and contextual barriers that have received limited systematic empirical investigation. This paper presents findings from a structured survey of 218 manufacturing SMEs across six industrial clusters in India (auto-components, textile machinery, machine tools, engineering plastics, food processing, and pharmaceuticals). An Analytical Hierarchy Process (AHP) framework was deployed to prioritise Industry 4.0 readiness dimensions, and Structural Equation Modelling (SEM) was employed to test a hypothesised barrier-adoption model. Results indicate that financial constraints (path coefficient β = 0.61), digital skill gap (β = 0.54), and lack of standardised infrastructure (β = 0.48) are the dominant adoption barriers. Technology awareness and managerial commitment emerge as significant moderators of adoption intent. Sector-wise analysis reveals notable heterogeneity: auto-component SMEs demonstrate significantly higher readiness (mean readiness score 3.82/5) compared to textile machinery SMEs (2.74/5). Policy implications and a tiered adoption roadmap for Indian manufacturing SMEs are proposed.

Keywords: *Industry 4.0, SME, Digital Transformation, AHP, Structural Equation Modelling, Adoption Barriers, Indian Manufacturing, IoT*

1. Introduction

The fourth industrial revolution — widely termed Industry 4.0 (I4.0) — is fundamentally reshaping global manufacturing through the integration of digital, physical, and biological technologies [1]. The I4.0 framework, first articulated at the Hannover Messe in 2011, encompasses nine enabling technology pillars: Industrial IoT, autonomous robots, simulation, horizontal and vertical integration, cloud computing, additive manufacturing, augmented reality, big data and analytics, and cybersecurity [2]. Together, these technologies promise substantial improvements in productivity, quality, flexibility, and energy efficiency in manufacturing operations.

India's manufacturing sector, which contributes approximately 16% of GDP and employs over 60 million workers, faces an urgent imperative to modernise in the face of increasing global competition and the disruption accelerated by the COVID-19 pandemic [3].

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SMEs constitute 95% of industrial units in India and contribute 45% of manufacturing output, yet their I4.0 readiness lags significantly behind large enterprises due to financial, technical, and managerial constraints [4]. Despite the strategic importance of Indian manufacturing SMEs, rigorous empirical studies quantifying I4.0 adoption barriers in the Indian context remain scarce, motivating the present investigation.

2. Conceptual Framework

2.1 Industry 4.0 Readiness Dimensions

Drawing from established I4.0 maturity and readiness models [5], this study conceptualises SME readiness across five dimensions: (1) Technology Infrastructure Readiness (TIR), (2) Digital Skill and Human Capital Readiness (DSR), (3) Strategic and Managerial Readiness (SMR), (4) Financial Readiness (FR), and (5) Ecosystem and Supply Chain Readiness (ESR). Each dimension was operationalised through validated multi-item Likert scales (1–5) adapted from the

IMPULS Industry 4.0 Readiness tool and modified for the Indian SME context through expert panel review (n = 12 industry and academic experts).

2.2 Research Hypotheses

The SEM model tested five primary hypotheses: H1 (Financial Readiness positively predicts I4.0 Adoption Intent), H2 (Digital Skill Readiness positively predicts Adoption Intent), H3 (Strategic Readiness positively predicts Adoption Intent), H4 (Ecosystem Readiness positively predicts Adoption Intent), and H5 (Technology Awareness moderates the relationship between Financial Readiness and Adoption Intent). All hypotheses were grounded in Technology Acceptance Model (TAM) and Innovation Diffusion Theory (IDT) frameworks.

3. Research Methodology

3.1 Survey Design and Sampling

A structured questionnaire comprising 48 items across the five readiness dimensions plus adoption intent was developed and pilot-tested with 30 SME managers. The final instrument was administered face-to-face and via email to senior managers (owners, CEOs, or production heads) of manufacturing SMEs in six industrial clusters. SMEs were defined per the Indian MSMED Act 2006 criteria (investment in plant and machinery: ₹25 lakh–₹10 crore for small; ₹10 crore–₹50 crore for medium). A stratified sampling approach ensured proportional representation across sectors. Of 312 questionnaires distributed, 218 usable responses were received (response rate: 69.9%).

Table 1: Respondent Profile by Sector

Sector	n	% of Total	Mean Readiness
Auto-components	48	22.0	3.82
Machine Tools	42	19.3	3.51
Pharmaceutical	36	16.5	3.44
Engineering Plastics	35	16.1	3.19
Food Processing	32	14.7	2.98
Textile Machinery	25	11.5	2.74
Total	218	100	3.29

3.2 Analytical Methods

AHP was applied to determine the relative importance weights of I4.0 readiness dimensions based on pairwise comparisons by the expert panel. The consistency ratio (CR) was maintained below 0.10 for all pairwise matrices, confirming judgement consistency. SEM was conducted using AMOS 24.0 with maximum likelihood estimation. Model fit was assessed using CFI (> 0.90), RMSEA (< 0.08), SRMR (< 0.08), and χ^2/df (< 3.0). Convergent validity was confirmed via AVE > 0.50 and composite reliability > 0.70 for all constructs.

4. Results

4.1 AHP Priority Weights

Financial Readiness emerged as the highest-priority dimension (AHP weight: 0.312), followed by Digital Skill Readiness (0.258), Strategic and Managerial Readiness (0.189), Technology Infrastructure Readiness (0.148), and Ecosystem Readiness (0.093). Figure 1 illustrates the proportional distribution of readiness dimension weights. This finding underscores that financial constraints — rather than technology availability — represent the primary I4.0 adoption barrier for Indian SMEs.

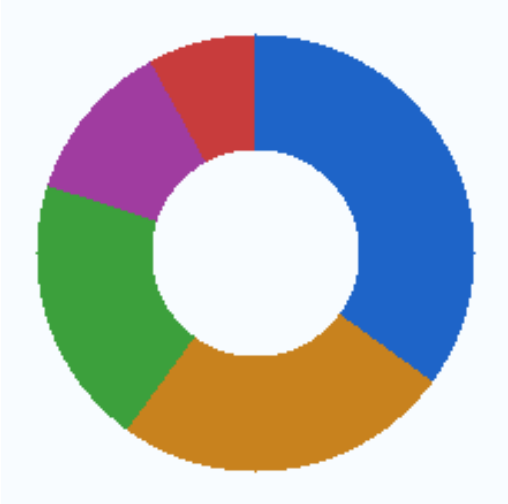

Figure 1: AHP Weight Distribution — I4.0 Readiness Dimensions
Source: Authors' AHP analysis, 2020

4.2 SEM Results

The SEM measurement model demonstrated good fit: CFI = 0.942, RMSEA = 0.061, SRMR = 0.058, χ^2/df = 2.34. All five hypotheses were supported at the 5% significance level. Financial Readiness exhibited the strongest path coefficient to Adoption Intent (β = 0.61, p < 0.001), followed by Digital Skill Readiness (β = 0.54, p < 0.001) and Strategic Readiness (β = 0.43, p < 0.001). The moderation analysis confirmed that higher Technology Awareness significantly amplifies the positive effect of Financial Readiness on Adoption Intent (interaction term β = 0.28, p = 0.009).

Table 2: SEM Path Coefficients and Hypothesis Results

Hyp.	Relationship	β	p-value	Supported
H1	FR → Adoption Intent	0.61	< 0.001	Yes
H2	DSR → Adoption Intent	0.54	< 0.001	Yes
H3	SMR → Adoption Intent	0.43	< 0.001	Yes
H4	ESR → Adoption Intent	0.31	0.002	Yes
H5	Tech. Awareness (mod.)	0.28	0.009	Yes

4.3 Sector-wise Readiness Comparison

Figure 2 presents the stacked readiness profile across the six surveyed sectors, decomposed by dimension. Auto-component SMEs demonstrate uniformly high scores across all dimensions, benefiting from OEM-driven digitalisation mandates and supply chain integration requirements. Textile machinery SMEs lag particularly in Digital Skill Readiness (mean: 2.31) and Technology Infrastructure Readiness (mean: 2.18), reflecting the predominantly artisan-craft character of this sector in the Indian context.

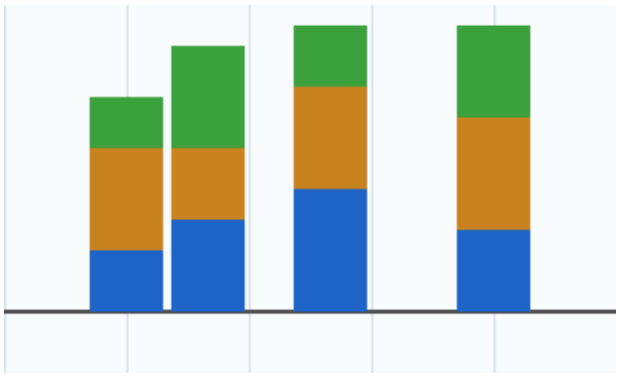

Figure 2: Stacked Readiness Profile by Sector and Dimension
Source: Authors' survey data, 2020

5. Conclusions

This empirical investigation provides a comprehensive, multi-sector quantification of I4.0 readiness and adoption barriers among Indian manufacturing SMEs. Financial constraint is the dominant barrier (AHP weight: 0.312; SEM β: 0.61), followed by the digital skill gap and strategic commitment. Sector heterogeneity is pronounced: auto-component SMEs are substantially more I4.0-ready than textile or food processing counterparts. The validated SEM framework offers a replicable instrument for tracking SME digitalisation progress. Policy implications include targeted financial incentive schemes, government-sponsored digital skill programmes, and cluster-level shared infrastructure initiatives to accelerate I4.0 adoption among resource-constrained Indian SMEs.

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