

Original Article

IoT Readiness in an Auto-Component SME: Barrier-Cost-KPI Prioritization using an Indian SME Readiness Index

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Abstract - Indian Small and Medium Enterprises (SMEs) face significant structural challenges in adopting the Internet of Things (IoT), despite its transformative potential for enhancing manufacturing quality and operational efficiency. Existing readiness models often overlook the integrated impact of barrier severity, firm-specific cost structures, and quality-centric Key Performance Indicators (KPIs) unique to emerging economies. This research develops the Indian SME Readiness Index (ISRI) to provide a comprehensive prioritization framework for IoT adoption. Employing a quantitative single-case study methodology, the ISRI was applied to an auto-component SME in Aurangabad serving global OEMs. The framework utilizes barrier scoring across 15 validated indicators, cost factorization across 20 balance-sheet categories, and strategic KPI mapping. Key findings: “future viability and profitability”, “lack of IoT standards/architecture”, and “knowledge management deficits” as the most critical barriers threatening Parts Per Million (PPM) rates and delivery reliability. These results imply that IoT interventions must be prioritized based on their direct impact on quality-related financial risks. The study’s primary contribution is the ISRI framework, which fills a critical gap in context-specific readiness assessments for Indian SMEs. Practically, it offers an Excel-based diagnostic toolkit for managers to align digital transformation with quality objectives. While limited by its single-case focus, the research provides a robust foundation for future multi-sector validation, enabling evidence-based policymaking for cluster-level industrial growth.

Keywords - Internet of Things, Industry 4.0, SMEs, Readiness Assessment, Key Performance Indicators.

1. Introduction

IoT is the driving force behind the digital revolution. IoT, data analytics, and automation are quickly changing manufacturing around the world by connecting people, processes, and physical assets. Manufacturers can use these new tools to make decisions based on data, make their processes more efficient, and quickly respond to changes in the market. A lot of research has gone into making readiness and maturity models to see how ready businesses are for Industry 4.0 because of this potential. The IMPULS Industry 4.0 Readiness Model from Germany is a good example. It looks at six areas of a business, like strategy, technology, and workforce, and sets a global standard for digital maturity [1, 2]. A comprehensive survey of existing Maturity Models revealed that while several frameworks exist for large-scale enterprises, they often lack the granularity for SMEs and fail to incorporate technological forecasting specific to emerging markets. It is usually large-scale companies and multinationals that are first placed in the position to access and utilize the digital technologies; the majority of businesses

within economies such as India belong to the SME sector. These SMEs play a role in the development of the economy and also the creation of jobs, but are at a disadvantage due to their inability to access IoT technologies. Indian SMEs are forced to address such problems as the absence of a budget, poor IT infrastructure, the absence of established IoT standards, and virtually no cybersecurity division. These issues become long-term problems as they are not able to access credit, capital costs are high, and their investment is not clear on which profit to be made. Indian SMEs are not digitally transformed, as there is barely any structure that can be adapted to suit their unique financial background, business needs, and approaches to business strategy. This makes them even more difficult to compete and fit in a market that is constantly evolving [3-8].

According to the existing literature, the majority of the models of IoT readiness do not consider financial limitations in detail, adequacy with the business KPIs and cost-related aspects of small and SME companies that operate in



developing nations. SIRI (Smart Industry Readiness Index) of Singapore bridges this gap, considering cost and KPI aspects along with organizational or technical aspects. This provides the full picture of how prepared SMEs are to take a digital leap and set priorities. There is a paucity of literature that supports ecosystem-level assessment, which considers technology, processes, people and supply chain relationship to produce assessment and transformation strategies that are most effective in the current situation [3, 7, 9, 10, 38, 40,]. The barriers to IoT adoption directly interfere with such key quality indicators in the cases of the OEM suppliers as high Parts Per Million (PPM) defect rates, decreased on-time delivery rates, and higher warranty rates because of unstable processes and the absence of quality monitoring in real-time. On-the-fly preparedness evaluation without quality KPIs, auto-component SMEs are at risk of being left behind by fully digital rivals using IoT to predict quality and stable processes, [11-13]. Three elements of barrier severity, cost factorization, and strategic KPI mapping are embedded in ISRI in a single quantitative framework of measurement of the IoT preparedness level.

This study focuses on Indian manufacturing SMEs. Empirical validation includes case data from several organizations, comparisons with global and regional readiness frameworks based on literature, and an examination of the technical, financial, regulatory, and ecosystem barriers that are unique to the Indian SME landscape. ISRI provides owners, practitioners, and policy-makers a useful roadmap for how to efficiently use resources and speed up digital transformation by systematically weighting and normalizing the effects of barriers, costs, and KPIs [1, 8, 9, 14, 15].

This study makes the following contributions:
Theoretical contributions:

- Proposes an Indian SME Readiness Index (ISRI) integrating barrier severity, cost factors, and quality-related KPIs within a unified quantitative framework.
- Extends Industry 4.0 readiness literature by embedding quality management principles and financial realism tailored for resource-constrained SMEs in emerging economies.

Practical contributions:

- Provides SME managers and quality practitioners with a step-by-step readiness assessment and barrier prioritization procedure via Excel-based ISRI toolkit.
- Offers policymakers a structured diagnostic tool for identifying and addressing SME digital quality improvement barriers at ecosystem/ cluster levels.

Though numerous frameworks for the readiness of Industry 4.0 and IoT have been suggested in literature, the majority of these studies have either been limited to maturity appraisal, barrier identification or organizational level variables. Very few studies merge the impact of the barriers

with the cost structure and strategic KPI priorities of SMEs into a single framework. This is relevant for Indian SMEs in the manufacturing sector, which have to deal with multiple issues, including financial constraints, poor digital infrastructure and pressure of customers who are driven by quality. The paper develops the Indian SME Readiness Index (ISRI) to tackle this issue. The ISRI brings together the barrier score, cost factor and KPI factor in order to better understand the IoT adoption barriers in a logical and actionable manner. This study is unique because of its combined logic of prioritization and empirical basis in the auto-component SME.

In contrast to previous models that mainly offer readiness scoring or barrier ranking, ISRI converts information derived from the survey regarding barriers, balance sheet cost, and KPIs chosen by the SME into a single value that reflects the impact. This permits the methodology to define not only the barriers but also their importance from a financial and strategic point of view for the company. This paper is structured as follows: Section 2 looks at global and Indian IoT readiness frameworks and points out important gaps. Section 3 outlines the approach for creating and putting ISRI into use. Section 4 provides detailed information on how to use and test the method with case studies of SMEs in India and its interpretation for important barriers - section 5 ends with concluding remarks.

2. Literature Survey

2.1. Global and Regional Industry 4.0/IoT Readiness Frameworks

The need for manufacturing companies to adopt IoT has led to the creation of many readiness and maturity models at the global and regional levels. Germany's IMPULS model assesses six areas (e.g., Smart Operations, Strategy) [16]. Additionally, the model proposed by [10] gave companies a different set of tools to capture their present status and make clear plans. Academic frameworks proposed by [9, 17], which helped by breaking down the complexity of IoT into small parts that could be measured and acted upon, [18] demonstrated how these frameworks could be used in different problems by using Indonesia as an example.

The SIRI [3] is one of the most important models. It is known for its structured 3-block, 8-pillar, 16-dimension approach. SIRI helps manufacturers measure their progress, set strategic goals, and use its Prioritization Matrix to combine cost factors, KPI factors and proximity-to-benchmark to rank improvement opportunities with an unprecedented level of detail. Recent studies have refined these initial models, enhancing their specificity and sensitivity within the SME context. [4] stressed the importance of data-driven services and the connection between using new technology and being able to stay in business in the future. The discussion reinforced a key idea in the ISRI framework. [19] discussed the unique financial and technical problems SMEs face, which is why there is a need for custom frameworks that take more than just

technological readiness into account. Quantitative and multi-criteria decision-making approaches, exemplified by the MCDM methods presented in [15], correspond directly with the weighted scoring and prioritization strategies implemented in the ISRI. The idea of a comprehensive, ecosystem-level assessment put forth by [7] is similar to the ISRI's goal of bringing together internal capabilities with external supply chain and customer factors. In India, most studies on readiness have looked at either qualitative assessments or just one area (like technology or process). There has been a significant deficiency in comprehensive, quantitative models that incorporate barriers, cost structures and business key performance indicators, a deficiency that the present study directly addresses. Another contribution to the assessment of Industry 4.0 maturity and readiness is the work of [20, 21], who created an important maturity scale just for SMEs. This scale shows how important human resource management is, in addition to adopting new technologies, filling in the gaps left by models that focus more on technology. They centered their approach on the challenges faced by SMEs when utilizing models designed primarily for larger enterprises.

The Digital Readiness Level (DRL) 4.0 model is introduced in [22] for small and medium enterprises in the manufacturing sector in Italy. The DRL model is simple to use and comprehends strategy, technology, people, processes, and integration into one definition. As a pilot project with 20 SMEs, the model has revealed that the level of readiness varies from company to company, indicating the necessity for certain contextual frameworks like ISRI. Furthermore, [23] introduced a detailed maturity framework and technology forecasting model for smart manufacturing companies, featuring a modular design that includes dimensions such as Factory 4.0, Logistics 4.0, Management 4.0, and Operator 4.0. Their work combines technological forecasting to predict growth in adoption, stressing the need for a structured roadmap for Industry 4.0 implementation. This is in line with ISRI's focus on strategic prioritization and dynamic readiness assessment.

2.2. Quality management perspective on IoT readiness

Industry 4.0 and IoT are increasingly interpreted through a quality management lens, where digital technologies enable continuous improvement and data-driven decision making. Recent quality research studies emphasize that digital readiness directly affects an organization's ability to stabilize processes, reduce variation, and sustain performance across product, process, and service quality dimensions. Recent work on the transition from Quality 4.0 to Quality 5.0 shows that Industry 4.0 technologies are pushing quality management towards more human-centric, sustainable and resilience-oriented systems, strengthening the need to align digital readiness with broader quality and quality-of-life outcomes [24]. From this perspective, key barriers addressed in the ISRI framework, such as lack of standards and reference architectures, weak knowledge management systems, and

deficits in worker and manager training, represent critical quality system weaknesses that manifest as poor standardization, fragile learning loops, and unstable processes, by combining barrier severity with cost and KPI factors that explicitly include quality-related metrics, ISRI positions IoT readiness assessment as a structured quality management tool that supports systematic, evidence based prioritization of improvement action in manufacturing SMEs [25-28].

2.3. Barriers to IoT/Industry 4.0 Adoption in SMEs

- The literature focuses on technological limitations, such as high-capital requirements, lack of IT infrastructure, accessibility issues, lack of standards, and data security issues, as well as the importance of vertical and horizontal integration and automation, [29-32].
- High implementation costs, limited access to financing and uncertainty in the returns on investment are part of the economic and Structural barriers in Indian SMEs, wherein personnel, materials, and maintenance constitute the highest cost as reflected by the SIRI and ISRI financial factor modelling [29, 33, 42].
- Legal and consumer factors like data privacy, compliance, and customer reluctance to share data are increasingly becoming obstacles, particularly in the context of Indian SMEs and the broader IoT adoption [29, 32, 34, 35].

The classification of barriers into human, financial, and organizational categories in this study builds upon the comprehensive framework validated in recent research on the Indian SME Sector. The incorporation of cost factorization and the prioritization of business KPIs into IoT readiness frameworks has been minimally explored in the literature, with significant exceptions such as the SIRI, which correlates specific cost categories and KPIs to distinct barriers, facilitating pragmatic, context-sensitive prioritization [3]. Indian research has underscored the necessity for readiness models to accurately represent the unique financial frameworks of the country and to facilitate SMEs in choosing KPIs that correspond with their strategic objectives, including productivity, quality, flexibility and growth. The ISRI's method, which includes clear normalization and weighting of cost and KPI parts along with barrier severity, fills this gap and makes readiness assessment more relevant to Indian SMEs [22, 32].

2.4. International and Indian Readiness Frameworks

To contextualize the proposed ISRI within the wider academic and practical framework, it is imperative to compare it with premier global and regional Industry 4.0/IoT readiness and maturity assessment frameworks. This comparison highlights areas of agreement and disagreement in existing models, and crucially, identifies research and practice gaps, particularly for small and medium-sized businesses in the Indian manufacturing sector. Table 1 shows a comparison of some international, regional, and Indian readiness/maturity

frameworks. This comparison aims to identify their essential characteristics, pinpoint their limitations or deficiencies, and elucidate how ISRI progresses by amalgamating barrier severity, cost factorization, and SME-chosen strategic KPIs into a cohesive, data-driven prioritization framework. Current readiness models mostly evaluate the maturity of the organization, technology, or strategy, and studies about

barriers mainly focus on identifying the limitations of uptake. However, very few studies have combined the severity of barriers with the specifics of the cost structures of SMEs and the priorities of strategic KPIs in a single quantitative framework. This leaves room for contextual prioritization in Indian manufacturing SMEs, which is covered by the ISRI with its barrier-cost-KPI approach.

Table 1. Comparison of various readiness/maturity frameworks for industry 4.0/IoT adoption

Framework/Study	Key Features	Gap/Comment
SIRI (Singapore) [3]	3-block, 8-pillar, 16-dimension readiness, cost & KPI integration	Customizable, but based on the Singapore context
German I4.0 Index [8]	Stepwise maturity on process, tech, org structure	Lacks explicit quantitative cost/KPI mapping
ISRI (Our Model)	Barrier score via weighted indicators, mapped cost factors, SME-chosen KPIs	First Indian framework to fully integrate these elements quantitatively
A Maturity Model for Industry 4.0 Readiness [30]	9 dimensions, including technology and organizational aspects; 62 items; tested tool with transparent scoring	A basic and well-known all-encompassing model that includes strategy, leadership, and culture, as well as technology.
IMPULS Industry 4.0 Readiness Model [1]	6 key dimensions: Strategy & Org, Smart Factory, Smart Operations, Smart Products, Data Services, Employees	German model that is practical and based on the needs of the industry, with a big picture view. This approach aligns with ISRI.
Framework for Industry 4.0 Readiness [5]	6 dimensions focused on data-driven services and future viability	Supports rationale for “Future viability & profitability” barrier in ISRI
Multi-Criteria Decision-Making for IoT Adoption in SMEs [32]	Uses MCDM techniques for technology prioritization in SMEs	Theoretically supports your weighted scoring methodology, combining barriers, cost, and KPIs
Smart Factory Readiness Model for SMEs [36]	Practical model tailored for SME financial and technical constraints	Justifies ISRI’s Cost Factor and KPI inclusion, focused on SME applicability
Holistic Digital Transformation Readiness Framework [7]	Integrates internal capabilities with the external ecosystem, including suppliers and customers	ISRI’s inclusion of integrated systems and customer confidence drivers represents this comprehensive and ecosystem-oriented viewpoint.
Company Compass (CCMS) 2.0 [37]	Six maturity levels across ten dimensions targeting manufacturing strategy, IT, and supply chain. Designed for a comprehensive readiness assessment.	Not generic for all sectors, but focused on manufacturing; tailored for the European industrial context.
Brazilian SME 4.0 Readiness [14]	Multi-dimensional framework for service-sector SMEs in Brazil; includes organizational, technological, and strategic factors.	Not focused on manufacturing and not validated outside of Brazil’s service sector.
RAMI 4.0 Model [34]	Reference architecture model mapping readiness on hierarchy, life cycle, and layers; widely used in global assessments.	Made mostly for German standards and big international companies; can be hard for smaller SMEs to use.
IJQRM Comprehensive Review & Framework [16]	Systematic review of 71 studies; distills top ten readiness dimensions, combines expert consensus and empirical data.	Not region-specific; aggregates literature, may overlook deep national context factors.
TOE Model for Indian IoT Adoption [15]	The Technology-Organization-Environment model, adapted for India, highlights government, interoperability, expertise, and funding.	The conceptual framework has been validated using data from an Indian firm; however, it does not provide explicit quantification of financial and KPI mapping.
Indian Barriers & Readiness Empirical Model [31]	Empirical, two-phase SME readiness and barrier framework with real Indian data; provides phased interventions.	It mostly uses barrier scoring and does not integrate KPIs and cost factors across the industry.

Ansari et al. (2023) [32]	An Industry 4.0 readiness model that assists in using new technologies by employing structured readiness dimensions.	It has not taken into account the expenses connected with SMEs.
Govindan & Arampatzis (2023) [35]	Comes up with a framework to measure readiness and barriers for Industry 4.0 implementation through a case-based approach.	Though the framework is useful for identifying barriers, it does not reveal the finances involved in implementation and the strategic importance of key performance indicators.
Srai & Co. (2023) [7]	It presents a comprehensive digital transformation readiness framework which connects internal organizational capabilities with those of suppliers, customers and the overall ecosystem.	It is expansive and strategic in nature, but not designed to be a basic diagnostic tool for small and medium enterprises, nor does it measure barriers, costs and KPIs.
Müller et al. (2024) [39]	Study introduces a framework that comprises barriers and enablers of Industry 4.0 in small and medium enterprises with the help of technological, organizational and environmental issues.	It focuses on the integration and supply chain, but even in this framework, barriers have not been converted to a weighted cost-KPI priority table.
Barbosa et al. (2024) [14]	The author offers an assessment method for Brazilian SMBs with detailed coverage of all aspects connected with Industry 4.0 implementation, including organizational, technological, and strategic.	However, the study is unique for Brazilian SMEs dealing with service industries and does not cover manufacturing or Indian SMBs
Jewapatarakul & Ueasangkomsate (2024) [6]	Investigates the impact of digital organizational culture, readiness, and knowledge acquisition on SMB digital transformation.	The study is strong in behavior and knowledge dimensions, but lacks a comprehensive evaluation of readiness score and budgetary elaboration.
Srebro & Jevtić (2024) [13]	Highlights the digitalization barriers experienced by rural and small businesses by employing a case-based methodology.	The accent is on the hindrances and operative hurdles, with no attention paid to the expenses.
OECD (2025) [41]	Survey reports its survey of small and medium enterprise digitalization in terms of using AI, fintech, sustainability tools and matters of digital security in various countries.	It has provided wide-ranging policy-based information, but has not yet offered a manufacturing-specific index.
Mayor Ravines et al. (2026) [42]	Framework bring a systematic review of the factors affecting the digital transformation of small and medium enterprises with the help of the TOE approach.	It is review-based and does not have an operational framework.

3. Research Methodology

Data collection occurred through the ISRI Framework Excel sheet submitted via email by the company, accompanied by explicit written (also via email) authorizing data analysis and publication while maintaining full confidentiality of the firm's identity and proprietary information. The unit of analysis is the firm as a whole, with data collected across three components: (1) barrier data comprising 2-3 specific indicators for each of the 15 validated barriers, (2) cost factor data extracted from balance sheet analysis (20 cost categories expressed as percentage of revenue), and (3) SME-selected strategic KPIs (6 out of 17 validated metrics) aligned with the firm's current operational maturity and strategic priorities.. This multi-source, three-component approach enhances construct validity and provides robust evidence for barrier

prioritization while maintaining contextual depth typical of single-case research.

3.1. ISRI Framework Overview and Component Structure

The manufacturing companies (and in particular Indian SMEs) face numerous obstacles, which complicate taking the full advantages of the IoT. Such challenges refer to technical, financial, organizational, and cultural challenges, all of which can contribute to the fact that it becomes more difficult to incorporate the use of IoT and gain the most out of Industry 4.0. It is highly significant to identify and overcome these barriers to come up with effective strategies of IoT, a smooth transition into digitalization, and long-term competitive edges. The proposed level of index of the ISRI gives Indian manufacturing SMEs a systematic, quantitative method of

measuring and ranking these issues. The ISRI is rooted in a rigid two-step research approach, and it is composed of three sections:

Barrier Score: It involves the direct organizational data to assess the seriousness of each of the barriers, which will demonstrate the extent to which a barrier reduces the pace of IoT adoption.

Cost Factor: Uses balance sheet data that is specific to SMEs to figure out how much each barrier costs.

KPI Factor: This measures how relevant each barrier is to important business goals and performance indicators to see how strategically important it is.

These three components are normalized, weighted, and aggregated to yield a composite impact value for each barrier, enabling data-driven prioritization (detailed in Sections 3.4-3.5). Then, the barriers are ranked so that targeted action can be taken where readiness interventions will have the greatest effect, as shown in Figure 1.

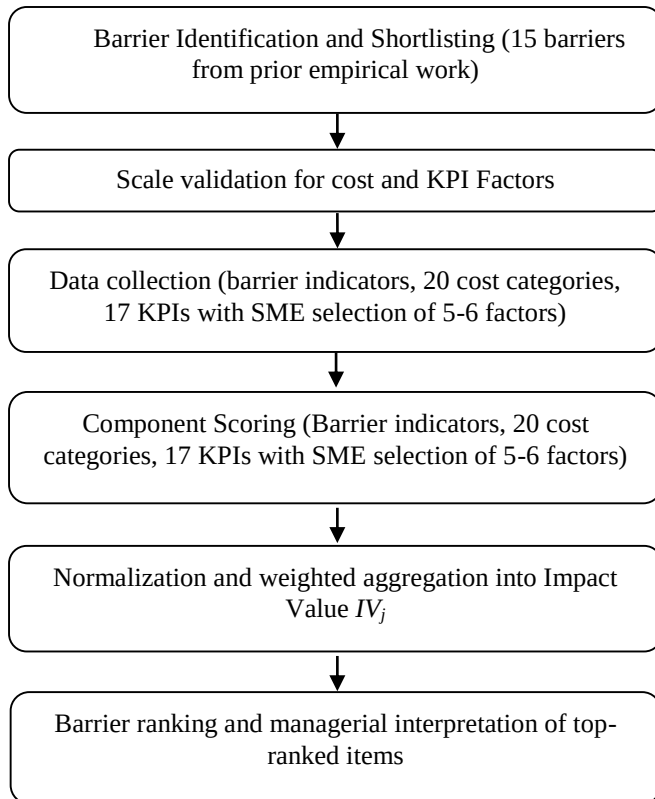


Fig. 1 ISRI conceptual framework flowchart

3.2. Barrier Identification and Shortlisting (Prior Study Phase)

An earlier empirical study found 35 barriers and 30 drivers to IoT adoption for Indian SMEs by looking at a lot of literature, talking to experts, and doing field surveys. These

elements were classified into eight thematic categories: human, financial, organizational, social, technological, security, legal, and customer-related. Thereafter, reliability analysis, bivariate correlation, and factor analysis were done, which led to the selection of the 15 most important barriers. The current ISRI model uses these shortlisted barriers as its main inputs.

3.3. Reliability Analysis of Cost and KPI Factors (Current Study Phase)

To verify the internal consistency and reliability of the constructs utilized in the ISRI, a reliability analysis was performed on the cost and KPI factor scales. The measure of reliability employed in this research was Cronbach's alpha. This measure is widely used for measuring internal consistency of multi-item scales [37, 43, 44].

The previous studies have established the reliability of the barrier characteristics, which means that the three components can successfully be combined to form ISRI.

3.3.1. Correlation-based mapping of Barriers to cost and KPI Factors

For the mapping of barriers with cost and KPI factors to be empirically justified, a bivariate Pearson correlation analysis was utilized and carried out on the data collected.

The correlation coefficients were then transformed into an ordinal scale to indicate the degree of significance of the association between barriers and respective cost and KPI variables.

The coding process was as follows: no relationship ($p \geq 0.05$) was coded as 0; a significant but weak relationship ($p < 0.05$, $|r| < 0.40$) was coded as 1; a significant and moderately strong relationship ($p < 0.05$, $|r| > 0.40$) was coded as 2; and a significant relationship ($p < 0.01$) as coded 3. The above codes were used in the ISRI workbook to develop barrier-to-cost and barrier-to-KPI correlation matrices.

This ensures that the final impact value is correctly calculated, taking into account both statistical correlation and the managerial relevance of the information provided by the correlation analysis. Some results of the bi-variate analysis of barrier-to-cost and respective coding are shown in Tables 2 and 3.

Table 2. Sample barrier-cost correlation matrix

	C3	C4	C5	C14	C15
B1	0.421**	0.40*	0.154	0.038	0.398**
B2	0.417**	0.238	0.284*	0.45	0.464**
B3	0.450**	0.208	0.490**	0.164	0.347**
B4	0.25*	0.158	0.161	0.32*	0.452**
B5	0.40**	0.2	0.284*	0.45*	0.34*

Table 3. Ordinal coding of barrier-cost correlation

	C3	C4	C5	C14	C15
B1	3	1	0	0	3
B2	3	0	1	2	3
B3	3	0	3	0	3
B4	1	0	0	1	3
B5	3	0	1	2	1

The same correlation-to-ordinal coding technique was used for correlation of the barrier-KPI relationships into consideration, and the final coded matrix was used in the ISRI workbook for deriving the KPI factor for each barrier.

3.4. Quantitative Barrier Prioritization

The ISRI framework turns the chosen barriers into a three-part composite index to find out which ones have the biggest effect on an SME's IoT readiness. There are three parts: Barrier Score, Cost Factor, and KPI Factor.

3.4.1. Barrier Score Calculation

The 15 essential barriers integrated into ISRI were selected through a prior, empirically validated study employing literature review, expert contributions, survey reliability (Cronbach's alpha), correlation, and factor analysis.

Each barrier is operationalized using three specific, measurable indicators that are appropriate for the SME context.

- **Indicator Selection:** Each barrier's three indicators gather data on specific organizational practices or outcomes related to the barrier.
- **Weight Assignment:** Industry experts assign relative importance weights (w_1, w_2, w_3) to each indicator within its barrier.
- **Calculation:**
 - i. Normalize the value of each indicator (as per the ISRI sheet methodology explained in Figure 1).
 - ii. Compute Barrier Score (BS) for each barrier as the weighted sum of its normalized indicators:

$$BS_j = \sum_{k=1}^3 W_k \times x_{jk,n} \quad (1)$$

where: BS_j = barrier score for barrier j ; k indexes indicators; $x_{jk,n} = x_{jk,N}$ = normalized value of indicator k for barrier j .

To verify the internal consistency and reliability of the constructs utilized in the ISRI, a reliability analysis was performed on the cost and KPI factor scales. The measure known as Cronbach's alpha coefficient was used as the measure of reliability because it is known as very effective at establishing the reliability of multi-item constructs [37, 43, 44]. The validity of the barrier constructs has already been known from previous studies, thus creating a strong basis for the integration of all three elements into the ISRI.

3.4.2. Cost Factor

The Cost Factor quantifies each barrier's financial salience using 20 cost categories directly extracted from the SME's balance sheet (adapting benchmarks from the Singapore SIRI index and Indian expert consultation).

- **Mapping:** Each cost category (e.g., labor, R&D, compliance) is mapped to relevant barriers through expert weighting.
- **Calculation:**
 - i. For each cost category: multiply its proportion of total costs by the mapping weight for each barrier.
 - ii. Cost Factor for a barrier is the sum across all relevant mapped cost categories:

$$CF_j = \sum_{i=1}^{20} (CostShare_i) \times (MappingWeight_{ij}) \quad (2)$$

where CF_j = cost factor for barrier j ; i Indexes cost categories.

3.4.3. KPI Factor

To ensure business alignment, SMEs select 5-6 KPIs most relevant to their strategy from a pool of 17 validated KPIs (e.g., asset efficiency, process quality, supply chain performance).

- **Mapping:** SMEs, guided by expert input, link their chosen KPIs to specific barriers (KPIs may map to multiple barriers).
- **Calculation:** For each barrier, the KPI Factor is the sum of mapping weights from all selected KPIs:

$$KPI_j = \sum_{i=1}^m (KPIMappingWeight_{ij}) \quad (3)$$

where KPI_j = KPI score for barrier j ; i indexes selected KPIs (m is the number of KPIs chosen by the SME).

3.5. Normalization

To aggregate scores, each component (Barrier Score, Cost Factor, KPI Factor) is normalized (min-max or sum normalization), ensuring values are on a common scale (typically).

- **Min-Max Normalization:** For component X (e.g., barrier scores):

$$X_{j,N} = \frac{X_j - \min(X)}{\max(X) - \min(X)} \quad (4)$$

- **Sum Normalization:** For proportion-based normalization:

$$X_{j,N} = \frac{X_j}{\sum_{j=1}^n X_j} \quad (5)$$

3.6. Weighted Aggregation

The normalized component scores are then combined using user/SME-selected weights, which reflect the company's digital transformation strategy or time horizon:

- Weights (W_{BS} , W_{CF} , W_{KPI}) can be set to prioritize immediate cost, long-term capability, or strategic KPIs as preferred.

Final Impact Value for each barrier (IV_j):

$$IV_j = W_{BS} \times BS_{j,N} + W_{CF} \times CF_{j,N} + W_{KPI} \times KPI_{j,N} \quad (6)$$

where: BSN = Normalized Barrier Score; CFN = Normalized Cost Factor KPIN = Normalized KPI Factor and WBS, WCF, WKPI = respective component weights.

Barriers are ranked in descending order of their Impact Value, with the top 3 barriers identified as the most critical for that SME.

4. Case Study: Application to an Indian SME

4.1. Instrument Validation

Cronbach's alpha values for the barrier, cost, and KPI factors were calculated to ensure that the measurement scales adopted in this research were congruent and reliable with each other. Table 4 below shows the exact values of Cronbach's alpha. Cost and KPI variables were adapted from the Singapore SIRI framework [3] and subsequently validated through input from Indian SMEs, confirming contextual relevance for the Indian manufacturing sector.

Table 4. Cronbach's value of barrier score, KPI and cost factor

Factor	Number of Items	Cronbach's Alpha
Barrier Score	35	0.886
Cost Factor	20	0.899
KPI Factor	17	0.913

4.2. SME Profile (Anonymized)

Sector: Auto-Component Manufacturing
Company Size: Medium (approx. 200 employees)
IT Maturity: Early-stage adoption (basic ERP; No IoT deployment)
Location: Aurangabad, Western India

The selected SME operates in a competitive Auto-Component manufacturing sector and faces typical constraints of an Indian mid-sized manufacturing organization, moderate digital maturity, budget restrictions for IoT, and strong pressure to modernize. The chosen SME is a competitive industry of Auto-Components manufacturing and has the common limitations of a mid-sized Indian manufacturing company, moderate digital maturity, constraints on financial means of IoT, and severe pressure to modernize. Theoretically and practically, it is a Tier-2 auto-component supplier that is

meaningful in terms of quality research. Operations to extreme quality needs of OEMs (100% on-time delivery, none are allowed as defective). The firm has harsh defect penalties and process capability very typical of Indian auto-component manufacturers, rendering IoT preparedness measurement especially pertinent in the context of attaining long-lasting quality changes-digital transformation.

4.3. SME Profile (Anonymized) Barrier Score Results

The 15 key barriers, determined through empirical research, were assessed using three indicators for each. Management interviews provided data specific to SMEs. To calculate the barrier score, here is an example: "Lack of training for workers and managers." To attain this score, normalize the values of the indicators, such as the percentage of untrained employees, the average number of training hours per year, and the amount spent on training as a percentage of revenue. Then add them all together to arrive at a number.

Step 1: Identify & Quantify Barrier Indicators

Three sample indicators (as per the ISRI framework) for B1:

- Indicator 1: Number of training programs offered per year.
- Indicator 2: Percentage of employees trained in digital technologies.
- Indicator 3: Budget allocation for employee training (Budget Allocated as % of total payroll, 5% considered to be a good budget)

Input given by SME:

- Number of training programs offered per year: 1 (Industry Average is 5)
- Percentage of employees trained in digital technologies: 12.5%
- Training and Skill Development Costs: 1.67% of total payroll

Step 2: Normalize the Indicator Value

We convert the raw data into a 0-1 scale where 1 represents the highest barrier (worst performance).

- Training Programs: $1 - (1 / 5) = 0.80$
- % Trained: $1 - (12.5 / 100) = 0.90$
- Budget: $1 - (1.67 / 5) = 0.333$

Step 3: Calculate the Weighted Score

Multiply the normalized value by the indicator's weight and then by 10 to scale it.

- Training Programs: $0.80 * 0.20 * 10 = 1.60$
- % Trained: $0.90 * 0.50 * 10 = 4.50$
- Budget: $0.333 * 0.30 * 10 = 1.00$

Thus final score is calculated as $1.60 + 4.50 + 1.00 = 7.1$.

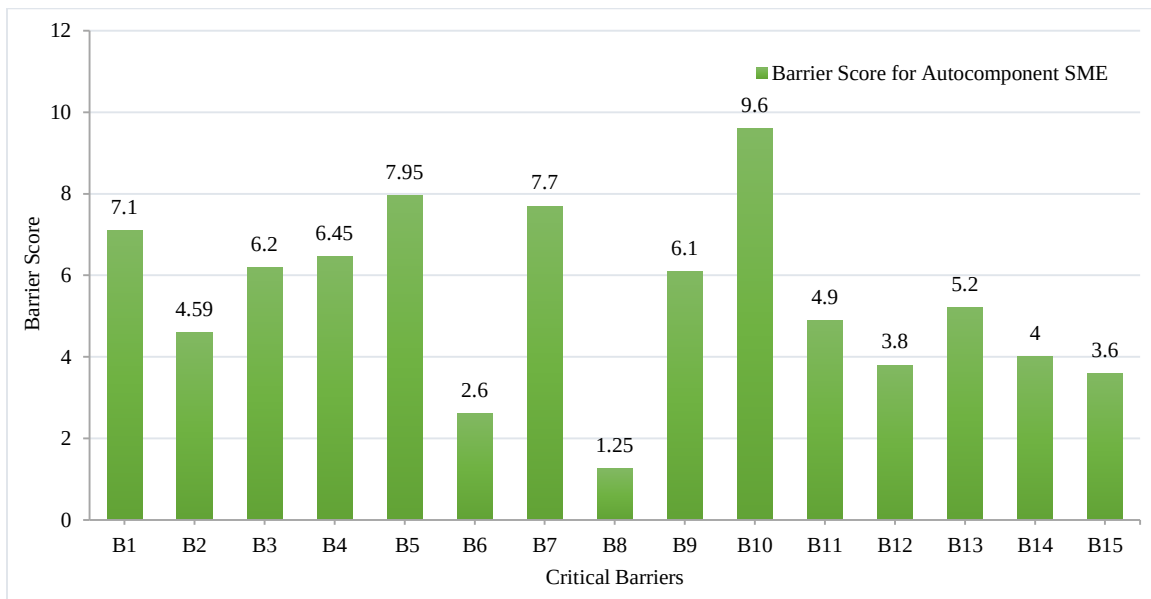
Similarly, the barrier score is calculated for the other 14 barriers as illustrated in Table 5.

Table 5. Barrier scores for selected indian SME

Sr.No.	Barrier	Barrier Score
1	Lack of training for workers and Managers-B1	7.1
2	Resistance to change-B2	4.59
3	Lack of digital culture and training-B3	6.2
4	Higher investment in employees' training- B4	6.45
5	Lack of knowledge management systems- B5	7.95
6	Regulatory compliance issues-B6	2.6
7	Lack of Standards and Reference Architecture-B7	7.7
8	Lack of Internet coverage and IT facilities-B8	1.25
9	Limited Access to Funding and Credit-B9	6.1
10	Future viability & profitability-B10	9.6
11	Dependency on External Vendors-B11	4.9
12	High Implementation Cost-B12	3.8
13	Compliance with Sector-Specific Regulations-B13	5.2
14	Lack of Regulations and Standards (Legal)-B14	4
15	Customers are hesitant to share data-B15	3.6

As illustrated in Figure 2, the barrier “Future Viability & Profitability” (B10) presents the highest hurdle with a score of 9.6 which limits investment in quality-enhancing digital systems such as part traceability and real-time in-process monitoring; lack of standards and reference architecture (B7, score 7.7) contributes to process variability, integration

defects, and non-conformities: lack of knowledge management systems (B5, score 7.95) leads to repeated quality problems, increased rework, and loss of tacit process knowledge; while training deficits (B1, score 7.1) manifest as higher defect rates, safety incidents, and inconsistent work practices-all critical threats to OEM quality requirements.

**Fig. 2 IoT barrier score in auto-component manufacturing SME**

4.4. Cost Factor Results

Measurement of the financial implications experienced by Indian SMEs due to identified barriers was done through 20 categories of costs. Of these, 10 cost categories were taken from the SIRI framework, while the other 10 cost categories were formulated based on the expertise of experts in order to bring out the nuances of Indian realities. The cost data selected covered a wide range of categories like manpower costs, material costs, direct and indirect, depreciation, cost of labour,

compliance costs, costs pertaining to training/awareness of issues, among others. A survey was also conducted to validate the relevance of these 20 cost categories as applicable to Indian SMEs before collecting the data. The information presented was in percentages of each cost category in relation to the total revenue of the SME. These values were converted to decimals to make sure that the arithmetic in the computation of the cost factors was accurate, as seen in Table 6.

Based on the data provided by industry professionals and domain experts, a relevance matrix was prepared that has assigned every one of 20 categories of costs to all 15 barriers. The input of the industry and expert opinion in each mapping had a weight relevance of 0 (no relevance), 1 (low), 2 (medium) or 3 (high).

The findings revealed the extent to which there was a correlation between a particular category of cost and each barrier. These scores were then Added together.

This systematic mapping, which was based on both financial data and relevance weighting based on industry knowledge, made it possible to accurately measure the cost factor for each barrier. The results showed how much each barrier would cost the SME in terms of IoT adoption. The cost factors mapped to barrier "Lack of training for workers and managers" are calculated by the cost metric of percentage annual revenue value multiplied by the barrier. Similarly cost factor was calculated for the other 14 barriers as illustrated in Table 7.

Table 6. Cost factor mapping with barrier

Category No.	Cost / Metric Category Description	Value (% of Annual Revenue)	Mapping with a barrier
1	Aftermarket Services / Warranty	0.005	0
2	Depreciation	0.05	0
3	Labour	0.05	2
4	Maintenance & Repair	0.01	0
5	Raw Materials & Consumables	0.75	0
6	Rental & Operating Lease	0.02	0
7	Research & Development (R&D)	0.01	2
8	Selling, General & Administrative Expense	0	1
9	Utilities	0.03	0
10	Earnings Before Interest & Taxes (EBIT) Calculated Result:	0.07	2
11	Financing Costs (Interest)	0.005	1
12	Taxation and Compliance Costs	0.002	1
13	Supply Chain and Logistics Costs	0.05	1
14	Technology and Digital Infrastructure Costs	0.01	3
15	Training and Skill Development Costs	0.001	3
16	Regulatory and Compliance Costs	0.002	1
17	Insurance Costs	0.005	1
18	Marketing and Customer Acquisition Costs	0	1
19	Environmental and Social Responsibility Costs	0	2
20	Quality Control and Assurance	0.01	1

Table 7. Cost factors - SME results

S.No.	Barrier	Cost Factor
1	Lack of training for workers and Managers-B1	0.367
2	Resistance to change-B2	0.276
3	Lack of digital culture and training-B3	0.287
4	Higher investment in employees' training- B4	0.297
5	Lack of knowledge management systems- B5	0.367
6	Regulatory compliance issues-B6	0.276
7	Lack of Standards and Reference Architecture-B7	0.276
8	Lack of Internet coverage and IT facilities-B8	0.276
9	Limited Access to Funding and Credit-B9	0.465
10	Future viability & profitability-B10	2.288
11	Dependency on External Vendors-B11	0.39
12	High Implementation Cost-B12	0.478
13	Compliance with Sector-Specific Regulations-B13	0.398
14	Lack of Regulations and Standards (Legal)-B14	2.298
15	Customers are hesitant to share data-B15	0.407

4.5. KPI Mapping Results

The SME chose six Key Performance Indicators (KPIs) as the most important for its IoT readiness and strategic priorities from a list of 17 KPI categories (10 categories adapted from SIRI and further 7 customized for Indian SME realities similar to cost factor), based on its needs: Asset & Equipment Efficiency, Inventory Efficiency, Process Quality, Supply Chain Efficiency, Market Share Growth, and Employee Productivity. The company gave these six chosen KPIs a value of "1" (meaning they should be included) and the rest a value of "0" (meaning they do not matter for this assessment).

This selective approach focused the analysis exclusively on the KPIs that most accurately reflect the SME's operational and strategic objectives. These KPI selections reflect the SME's quality strategy and OEM customer requirements, prioritizing process quality (defect reduction, capability improvement), supply chain efficiency (100% on-time delivery), and asset efficiency (OEE > 85%) to meet stringent automotive standards while balancing growth and productivity goals. Process Quality and Supply Chain Efficiency KPIs directly address core quality management objectives, ensuring IoT initiatives target defect prevention and delivery reliability critical for Tier-2 supplier contracts.

Table 8. KPI factor mapping with barrier

Category No.	KPI Categories	Input from SME	Mapping with a barrier
1	Asset & Equipment Efficiency	1	1
2	Utilities Efficiency	0	1
3	Inventory Efficiency	1	1
4	Process Quality	1	2
5	Product Quality	0	2
6	Safety & Security	0	1
7	Planning & Scheduling Effectiveness	0	2
8	Time to Market	0	1
9	Production Flexibility	0	2
10	Customer Satisfaction	0	1
11	Supply Chain Efficiency	1	1
12	Market Share Growth	1	2
13	Employee Productivity	1	3
14	Return on Investment (ROI)	0	2
15	Financial Health and Stability	0	2
16	Talent Retention	0	3
17	Customer Retention Rate	0	2

Table 9. KPI factors results

S.No.	Barrier	KPI Factor
1	Lack of training for workers and Managers-B1	6
2	Resistance to change-B2	6
3	Lack of digital culture and training-B3	6
4	Higher investment in employees' training- B4	6
5	Lack of knowledge management systems- B5	6
6	Regulatory compliance issues-B6	4
7	Lack of Standards and Reference Architecture-B7	4
8	Lack of Internet coverage and IT facilities-B8	5
9	Limited Access to Funding and Credit-B9	5
10	Future viability & profitability-B10	9
11	Dependency on External Vendors-B11	6
12	High Implementation Cost-B12	4
13	Compliance with Sector-Specific Regulations-B13	4
14	Lack of Regulations and Standards (Legal)-B14	4
15	Customers are hesitant to share data-B15	4

A process that was formed by which involved direct contribution of the SME owner as well as professionals in the field resulted in the generation of a relevance matrix, which interconnected these six KPIs to the 15 barriers. The score of

each mapping in the matrix was the degree of relevance: 0 (not relevant), 1 (low relevance), 2 (medium relevance) and 3 (high relevance). This made the connections of KPIs and barriers based on the worldview and values of the practitioners. In

order to calculate the KPI factor of every barrier, the values that were used were those of SME, which are provided in Table 8. The products were then summed up in the six selected KPIs to come up with a composite KPI factor for each barrier, as indicated in Table 9.

4.6. Final ISRI Scores

Each factor (Barrier Score, Cost Factor, KPI Factor) was normalized, weighted, and combined as per the chosen company strategy were weights of Cost factor, KPI factor and Barrier score were chosen as 0.3, 0.3 and 0.4. Sample calculation for barrier 10 “Future viability & profitability” is as explained below: -

Step 1: Identify the Three Input Factors and Normalize them. According to the ISRI methodology, the impact

value for each barrier emerges from a combination of three key factors: Barrier score, cost factor and KPI Factor. The normalized value is calculated as shown in Table 10.

Step 2: Impact value Calculation

The ISRI approach calculates a composite impact value for each barrier using the formula mentioned in section 3.5 of the methodology.

$$IV_j = W_{BS} \times BS_{j,N} + W_{CF} \times CF_{j,N} + KPI_{j,N} \quad (6)$$

$$IV_j = 0.4 \times 0.1640 + 0.3 \times 0.063 + 0.3 \times 0.0982 \\ = 0.1075$$

Similarly impact value for the other 14 barriers is as illustrated in Table 11.

Table 10. Normalized value calculation: Barrier Score, Cost Factor and KPI Factor

Metric	Value	Total Value	Normalized Value
Barrier Score	9.60	81.04	9.60/81.04= 0.118
Cost Factor	2.288	9.146	2.288/9.146= 0.2501
KPI Factor	9	79	9/79=0.1139

Table 11. Final ISRI impact values

Sr.No.	Barrier	Impact Value
1	Lack of training for workers and Managers-B1	0.0465
2	Resistance to change-B2	0.0373
3	Lack of digital culture and training-B3	0.0442
4	Higher investment in employees' training- B4	0.0454
5	Lack of knowledge management systems- B5	0.0531
6	Regulatory compliance issues-B6	0.0250
7	Lack of Standards and Reference Architecture-B7	0.0893
8	Lack of Internet coverage and IT facilities-B8	0.0216
9	Limited Access to Funding and Credit-B9	0.0455
10	Future viability & profitability-B10	0.1075
11	Dependency on External Vendors-B11	0.0411
12	High Implementation Cost-B12	0.0342
13	Compliance with Sector-Specific Regulations-B13	0.0382
14	Lack of Regulations and Standards (Legal)-B14	0.0307
15	Customers are hesitant to share data-B15	0.0319

4.7. Interpretation: Top Barriers and Discussion

Compared to previous techniques, the ISRI proposed in this paper yields enhanced decision-making value because it does not consider barriers as separate entities. Instead, the model combines the severity of the barrier, exposure to cost, and relevance of the KPIs into a single composite value, hence providing a concurrent view of the impact of each barrier from the operational, monetary, and strategic perspectives. In comparison, most previous publications rate the various barriers or determine the readiness solely on the basis of expert opinions or maturity dimensions without taking into account the unique preferences of SMEs operating in the Indian manufacturing sector. The correlation-based mapping approach added an extra layer of analytical rigor to the ISRI

model by linking the barrier variables to cost and KPI constructs through the statistical relationships derived from the survey responses. Consequently, the relevance matrices did not rely solely on expert decision-making, as they also factored in the strength and significance of the relationships identified in the SME database. Thus, the final impact results were consistent with a more reasonable prioritization process, whereby barriers that displayed a higher degree of empirical link with financial risk and strategic KPIs were treated with greater importance in the final ranking. The practical credibility of the Excel toolkit is strengthened, as the ranked barriers correlate with the operational evidence and managerial confirmation received from the CEO of the Auto-Component Manufacturing SME involved in the case study.

Final Impact value of barriers for this SME is as illustrated in Figure 3, and the five most 5 critical barriers are discussed.

- **Future Viability & Profitability (Impact Value: 0.1075, Barrier Score: 9.60, Cost Factor: 2.288, KPI Factor:9):** This barrier is the most important thing that is stopping this small business from using IoT. The highest barrier score and KPI factor show that managers are distressed about whether digital transformation can give them long-term competitive advantages and keep their business going for a long time. The very high cost factor makes it clear that uncertainty about future returns, despite a large up-front investment in IoT, can put the long-term health, profitability, and even survival of a business at risk in a market that is always changing. The close relationship between high-value KPIs (like growth, financial health, and ROI) and direct implementation costs means that SME leaders need to pay attention right away and change their strategy.
- **Lack of Standards and Reference Architecture (Impact Value: 0.0893, Barrier Score: 7.7, Cost Factor:0.276, KPI Factor:4):** this barrier has been rated as high, indicating the degree to which confusion is in relation to the IoT interoperability and lack of standardized frameworks. Such a lack poses a practical dilemma for SMEs, who must wait until there are clearer industry specifications, and this can cause delays or poor technology decisions. Areas that demand systematized systems to scale or integrate are subject to intense stress, respectively. This is a risk of obsolescence or low return on investment.
- **Absence of Knowledge Management Systems (impact value:0.0531, Barrier Score: 7.95, Cost Factor: 0.367, KPIFactor:6):** The absence of Knowledge management systems demonstrates a large internal issue: there is no great way of capturing, sharing, and utilizing knowledge of an organization. The company continues to commit errors and its uncoordinated approach to digitalizing the company due to the inability of most of the employees to access centralized data and best practice repositories. Such access in the IoT world results in a sluggish completion of a project, a lack of consistency and flexibility, meaning that the SME may find it difficult to maintain high standards and adapt to change.
- **Deficit in Worker and Manager Training (Impact Value: 0.0465, Barrier Score: 7.1, Cost Factor:0.367, KPI Factor:6):** The high score of the barrier indicates that the workforce lacks skills and the managers are not prepared to use IoT. This issue continues to occur due to the firms' failing to spend adequate funds on training their workers and failing to appreciate the importance of continuous training. The final effect is sustained skill gaps, unwillingness to innovate, and disappointing outcomes of new technologies, which directly damage the KPIs of the greatest significance to digital success.
- **Difficult access to Financing and Credit (Impact Value: 0.0455, Barrier Score: 6.1, Cost Factor:0.465, KPI Factor:5):** The major factor why this small business is not using IoT is financial problems. Although the barrier and KPI scores are large, a high price point indicates that issues that receive funding must face the difficulties of purchasing the technology and training necessary with high cost. Unless the company can obtain better access to capital, it might not be able to fulfill its digital transformation objectives, which will damage its competitiveness and survival.

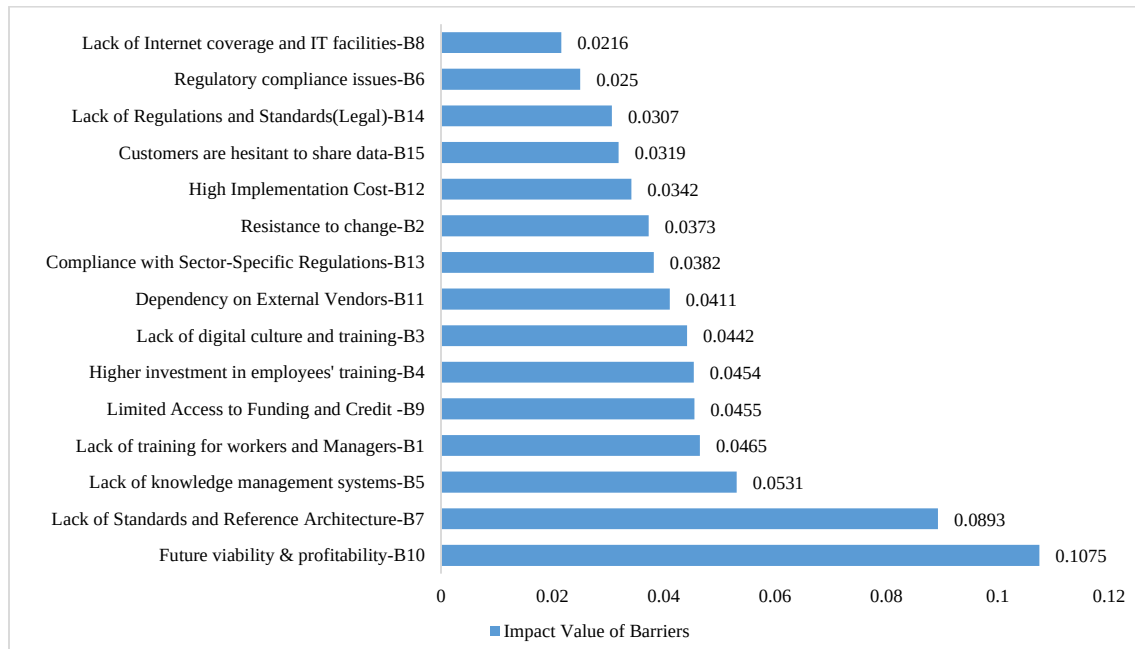


Fig. 3 Final impact value for barriers

5. Conclusion

This study validates the Indian SME Readiness Index (ISRI) through application to an auto-component manufacturing SME in Aurangabad, demonstrating how barrier severity (B10: 9.6), cost structures, and strategic KPIs can be systematically integrated for impact-based prioritization. The analysis identified future viability and profitability, lack of IoT standards, and knowledge management deficits as the top barriers, with direct implications for quality outcomes, including PPM reduction, process stability, and OEM compliance. ISRI's Excel-based implementation proved practical for SME use while maintaining methodological rigour (Cronbach's $\alpha > 0.886$ across constructs). Through the analysis, it is also revealed that many issues of Indian SMEs are related to their organizations, including a lack of good knowledge management systems, over-dependence on external vendors, and a lack of an adequate skilled labour force. These issues reveal that the company must drastically change its processes and culture, and not simply purchase new technology.

Moreover, the add-on of the fact that the gaps in training and change management remain demonstrates that the human and cultural barriers are, nevertheless, as crucial as the technical or financial. The significance of the ISRI is in the ranking of barriers and demonstrations of the most significant total influence, and requires special attention in the short term. Executives should collaborate to solve these big problems by putting resources where they will most likely benefit, advocating for better regulations and fostering deep partnerships in the digital ecosystem. ISRI is a diagnostic and practical guide to practitioners, policymakers and leaders of SMEs. It assists them in monitoring their rates of transformation into being digitally prepared, utilizing their investments optimally, and developing the human resources

that they must have to make long-term change. This research connects theory and practical application by going beyond simple counting to structured, data-driven prioritization. The ISRI helps Small and Medium-Sized Businesses (SMEs) in India advance past their digital inertia and take advantage of the IoT's ability to boost productivity, resilience and innovation in the new digital economy.

Implication for Quality Management

The ISRI framework offers quality practitioners four practical benefits: -

- Prioritized action planning: Targets interventions to the highest-impact barriers affecting quality outcomes (standards, training, knowledge systems).
- Financial justification: Links IoT investments to concrete cost savings and quality KPI improvements, facilitating SME buy-in.
- OEM compliance roadmap: Aligns digital readiness with automotive quality requirements (PPM reduction, delivery reliability).
- Cluster-level scalability: Enables coordinated quality improvement across SME supplier networks.

Conflicts of Interest

Authors declare that they have no known competing financial or personal relationships that could have appeared to influence the work reported in the paper.

Consent Declarations

Throughout the study, strict ethical considerations were observed. Informed consent was obtained from all survey and data anonymity and confidentiality were maintained to protect the privacy of respondents.

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