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Development of an Industry 5.0 Implementation Framework for Small Manufacturing Industries

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Abstract: ***Industry 5.0 extends the automation-centric vision of Industry 4.0 by placing human well-being, environmental resilience, and organisational sustainability at the core of manufacturing transformation. While large enterprises have begun piloting collaborative robotics, human-centric artificial intelligence, and circular production models, Small Manufacturing Industries (SMIs) continue to lag behind because of capital constraints, limited digital skills, and the absence of a structured adoption pathway suited to their scale of operation. This paper develops a practical, phase-wise Industry 5.0 Implementation Framework tailored to the resource realities of small manufacturing units, drawing on a structured review of recent literature and field-level observations from small manufacturing clusters in Maharashtra. The proposed framework organises implementation around five pillars — human-centricity, resilience, sustainability, technology integration, and governance — operationalised through four progressive maturity phases: Awareness and Readiness, Foundational Digitalisation, Human-Centric Automation, and Sustainable Optimisation. A readiness-assessment instrument and a barrier-mitigation matrix are proposed to help SMI owners self-diagnose their starting point and select low-cost, high-impact interventions. The framework is discussed against common barriers reported for small manufacturers, including financial constraints, workforce skill gaps, and limited managerial bandwidth, and mitigation strategies such as shared-resource models, cluster-based financing, and government skilling schemes are outlined. The paper concludes that a phased, human-centred, and cluster-supported approach can make Industry 5.0 adoption feasible for small manufacturers without requiring the capital intensity typically associated with digital transformation, and it identifies directions for future empirical validation of the framework across sectors.***

Keywords: Industry 5.0; Small Manufacturing Industries; Implementation Framework; Human-Centric Manufacturing; Digital Transformation; SME Readiness; Sustainable Manufacturing.

I. INTRODUCTION

The global manufacturing landscape has moved through successive waves of transformation, from mechanisation and mass production to computer-integrated manufacturing and, most recently, the cyber-physical integration associated with Industry 4.0. Industry 4.0 concentrated on connectivity, data-driven automation, and efficiency, often treating the human operator as a variable to be optimised out of the process.

The European Commission's articulation of Industry 5.0 reframes this trajectory by positioning the worker, the environment, and organisational resilience as co-equal objectives alongside productivity, encouraging manufacturers to design systems around human capability rather than replacing it outright.

For large manufacturing corporations, this shift is already visible in pilot deployments of collaborative robots, exoskeletons, and AI-assisted decision support that keep skilled workers in the loop. Small Manufacturing Industries (SMIs), however, form the overwhelming majority of manufacturing establishments in economies such as India, and they typically operate with thin margins, limited access to capital, minimal in-house technical expertise, and owner-driven decision-making structures. These constraints make the wholesale adoption of Industry 5.0 technologies impractical if the transformation is approached as a single large investment rather than a staged journey.

The central problem this paper addresses is the absence of an implementation pathway calibrated to the operating reality of small manufacturers. Existing Industry 5.0 literature is dominated by conceptual frameworks aimed at large, well-resourced organisations or by policy-level discussions of what Industry 5.0 should achieve, with comparatively little practical guidance on how a small manufacturing unit — often a single-owner workshop or a family enterprise with fewer than fifty employees — can begin the transition with the resources it actually has.

A. Objectives of the Study

1) To review the conceptual foundations of Industry 5.0 and its distinguishing dimensions relative to Industry 4.0.
2) To identify the specific barriers that constrain Industry 5.0 adoption in small manufacturing industries.
3) To develop a phased, resource-sensitive Industry 5.0 implementation framework suited to small manufacturing units.
4) To propose a readiness-assessment approach and barrier-mitigation strategies that support practical adoption of the framework.

II. LITERATURE REVIEW

A. Conceptual Evolution: From Industry 4.0 to Industry 5.0

Industry 4.0 research has largely centred on cyber-physical systems, the Internet of Things, big data analytics, and autonomous automation aimed at maximising throughput and minimising human intervention. Reviews of Industry 4.0 adoption in small and medium manufacturing enterprises consistently report that such firms face economic, technical, and cultural barriers that slow down digitalisation even when a clear roadmap exists. Industry 5.0 does not discard these technological foundations; rather, it reorients their purpose toward three complementary goals recognised across recent scoping and systematic reviews: human-centricity, resilience, and sustainability, while continuing to draw on enabling technologies such as artificial intelligence, big data analytics, and the Internet of Things.

B. Industry 5.0 in Small and Medium Enterprises

Recent scoping reviews of Industry 5.0 implementation in SMEs note that the transition demands substantial internal change, including the adoption of advanced technologies, redesign of production and strategic processes, and workforce upskilling, and that this burden falls disproportionately on smaller firms which, unlike large corporations, rarely have spare capacity to run experimental or pilot projects without risking core operations. Empirical work in this space also highlights a persistent gap between the ambition of conceptual Industry 5.0 frameworks and the actual readiness, competence, and organisational maturity observed in small manufacturers, with some studies pointing to genuine gains in resilience and human-centricity from automation and artificial intelligence, and others cautioning about risks such as workforce stress or displacement when these technologies are introduced without adequate preparation.

Adoption-oriented studies have proposed models that combine organisational viability thinking with technology-organisation-environment perspectives to help SMEs evaluate vulnerabilities before adopting new technology, demonstrating that gradual, context-sensitive adoption is both feasible and more sustainable than large-scale simultaneous change. Other work applying a supply-chain lens finds that Industry 5.0 technologies can improve visibility, real-time analytics, and collaboration for smaller manufacturers, provided the adoption process is matched to the firm's existing capability rather than imported wholesale from large-enterprise models.

C. Human-Centricity and Workforce Considerations

A recurring theme in the literature is that human-centred design in small factories remains under-specified: studies analysing requirements and barriers for human-centred SMEs argue that existing guidance rarely translates the abstract principle of human-centricity into concrete design or process requirements that a small factory can act on, and propose structured, requirement-based approaches as a way to close this gap.

D. Strategic and Governance Frameworks

At the strategic level, recent work proposes structured process models — combining phased implementation stages with lightweight management tools such as objectives-and-key-results tracking and dedicated competency-building phases — as being particularly well suited to smaller manufacturing organisations, even though such conceptual strategy frameworks remain more discussed among policymakers and researchers than actively adopted on factory floors, partly because many small and medium enterprises are still unaware of what Industry 5.0 requires of them in practice.

E. Toolkits and Assessment Instruments

Practitioner-oriented initiatives have also begun to emerge, including maturity-assessment tools that let a small manufacturer evaluate its current standing across human-centric, resilient, and sustainable dimensions and generate a phased rollout blueprint accordingly. These developments reinforce the case for a maturity-based, self-assessable approach rather than a one-size-fits-all technology checklist.

F. Synthesis and Positioning of This Study

Taken together, the literature converges on three points relevant to this paper: first, Industry 5.0 is conceptually well defined around human-centricity, resilience, and sustainability; second, small manufacturers face distinct resource, skill, and organisational barriers that large-enterprise frameworks do not adequately address; and third, phased, assessment-driven, and lightweight implementation approaches are consistently recommended as more realistic for smaller firms than large simultaneous transformation programmes. This paper builds directly on this convergence by translating these principles into an operational, phase-wise framework specifically scoped to small manufacturing industries.

III. RESEARCH GAP

Despite growing academic interest in Industry 5.0, three gaps remain evident from the review above. First, most frameworks are pitched at a conceptual or policy level and do not translate into a sequence of actionable steps for a resource-constrained manufacturer. Second, the specific barriers faced by small manufacturing industries — as distinct from medium or large enterprises — are under-represented in framework design, despite small units forming the largest share of manufacturing establishments in many developing economies. Third, there is limited guidance on how a small manufacturer can self-assess its readiness and select interventions proportionate to its size, rather than adopting a generic technology roadmap designed for larger organisations. This paper addresses these gaps by proposing an implementation framework that is phased, self-assessable, and explicitly scoped to the operating constraints of small manufacturing units.

IV. RESEARCH METHODOLOGY

This study adopts a conceptual and design-oriented research methodology, appropriate for developing an implementation framework rather than testing a statistical hypothesis. The methodology proceeds in four stages.

A. Stage 1 — Literature Synthesis

A structured review of recent peer-reviewed and practitioner literature on Industry 5.0, SME digitalisation, and human-centric manufacturing was conducted to identify recurring dimensions, barriers, and enabling practices, as summarised in Section 2.

B. Stage 2 — Contextual Observation

Informal field observations and interactions with small manufacturing units operating in and around industrial clusters in Maharashtra (covering sectors such as light engineering, sheet-metal fabrication, and machine-component manufacturing) were used to ground the framework in practical constraints such as owner-operator decision structures, limited IT infrastructure, and dependence on contract or seasonal labour.

C. Stage 3 — Framework Development

Insights from the first two stages were consolidated into a five-pillar, four-phase framework (Section 5), designed so that each phase requires a bounded, proportionate level of investment and can be initiated using resources already available to a typical small manufacturer, such as existing staff, basic connectivity, and low-cost sensing or record-keeping tools.

D. Stage 4 — Illustrative Validation

The framework's practical relevance is illustrated through an indicative case narrative (Section 6) describing how a small light-engineering unit could progress through the four phases, along with a readiness-assessment instrument that a manufacturer can use to locate its current maturity level. This illustrative approach is intended as a first step; Section 8 identifies full empirical validation across multiple firms as a direction for future research.

V. PROPOSED INDUSTRY 5.0 IMPLEMENTATION FRAMEWORK

The proposed framework rests on five pillars, drawn from the convergence identified in the literature review, and is operationalised through four progressive phases so that a small manufacturer can enter the journey at whatever level of readiness it currently has, rather than needing to adopt every element simultaneously.

A. *Five Pillars of the Framework*

- Human-Centricity — designing tasks, tools, and workstations around operator well-being, skill development, and safety, so that technology augments rather than displaces the workforce.
- Resilience — building the operational flexibility to absorb supply, demand, or workforce disruptions without halting production.
- Sustainability — reducing material waste, energy consumption, and emissions through process-level and equipment-level improvements suited to small-batch production.
- Technology Integration — introducing digital and automation tools in proportion to the firm's scale, beginning with low-cost digitalisation before layering in advanced automation.
- Governance and Culture — establishing simple decision-making, data-recording, and continuous-improvement practices that sustain the transformation beyond the initial investment.

B. *Four-Phase Maturity Model*

Each phase below is deliberately scoped to require modest investment, reflecting the resource ceiling typical of small manufacturing units. Progression to the next phase is intended to be gated by the readiness assessment described in Section 5.4, not by a fixed calendar timeline.

Phase	Focus	Representative Actions	Approx. Investment Level
Phase 1: Awareness and Readiness	Building leadership and workforce understanding of Industry 5.0 principles	Owner/manager orientation sessions; basic digital-literacy training; mapping of current processes and pain points; readiness self-assessment	Low (training time; minimal cost)
Phase 2: Foundational Digitalisation	Establishing a reliable data and process backbone	Digital record-keeping for production and maintenance; basic sensors on critical machines; simple dashboards for output and downtime tracking	Low–Moderate
Phase 3: Human-Centric Automation	Introducing automation that keeps operators central to decision-making	Semi-automated or collaborative equipment on bottleneck operations; ergonomic workstation redesign; skill-based task reallocation; safety sensors	Moderate (shared/leased equipment where feasible)
Phase 4: Sustainable Optimisation	Continuous improvement in resilience, sustainability, and performance	Energy and waste monitoring; predictive maintenance using collected data; supplier and demand flexibility planning; periodic framework re-assessment	Moderate–Ongoing (largely process-driven)

Table 1: Four-Phase Industry 5.0 Maturity Model for Small Manufacturing Industries

C. *Structural View of the Framework*

Figure 1 (described below) represents the framework as a layered structure: the five pillars run horizontally across all four phases, indicating that human-centricity, resilience, sustainability, technology integration, and governance are addressed at every stage rather than being sequential themes. The four phases run vertically, representing increasing technological and organisational maturity. A feedback loop connects Phase 4 back to the readiness assessment, reflecting that Industry 5.0 adoption is treated as a continuous-improvement cycle rather than a one-time project.

D. *Readiness-Assessment Instrument*

To help a small manufacturer identify its current phase, the framework proposes a lightweight self-assessment across the five pillars, scored on a simple three-level scale, as summarised in Table 2. A firm scoring predominantly at Level 1 should begin at Phase 1; predominantly Level 2 scores indicate readiness for Phase 2 or 3 initiatives; and predominantly Level 3 scores suggest the firm is positioned to pursue Phase 4 optimisation activities.

Pillar	Level 1 (Emerging)	Level 2 (Developing)	Level 3 (Established)
Human-Centricity	No formal skill or ergonomics plan	Ad hoc training and safety measures	Structured upskilling and ergonomic design in place
Resilience	Single supplier/process dependency	Some backup processes identified	Documented contingency and flexible capacity
Sustainability	No tracking of waste/energy	Informal waste-reduction efforts	Monitored energy/waste metrics with targets
Technology Integration	Manual/paper-based records	Partial digital tracking	Sensor-based monitoring and dashboards in use
Governance and Culture	Owner-only decisions, no data use	Some data used for decisions	Data-informed, continuous-improvement culture

Table 2: Industry 5.0 Readiness-Assessment Matrix for Small Manufacturing Industries

VI. ILLUSTRATIVE APPLICATION

To demonstrate practical relevance, consider an indicative small light-engineering unit with approximately twenty-five employees, producing precision-machined components for regional customers, and operating with largely manual record-keeping. Applying the readiness matrix (Table 2), such a unit would typically score at Level 1 on technology integration and governance, and Level 2 on human-centricity, given that many owner-operators already maintain informal safety practices.

Following the framework, the unit would begin at Phase 1 with a short orientation for the owner and supervisors on Industry 5.0 principles and a mapping of current bottlenecks, most commonly excessive machine downtime and inconsistent quality on a small number of critical operations. In Phase 2, the unit would introduce basic digital logging of machine downtime and output, using low-cost tablet-based forms rather than paper registers, generating the first structured dataset the firm has had on its own operations. In Phase 3, the highest-bottleneck machine could be fitted with a semi-automated feed mechanism operated collaboratively by the existing machinist, whose role shifts toward monitoring and quality verification rather than manual loading, supported by targeted upskilling. In Phase 4, the accumulated downtime and quality data would be used to plan preventive maintenance schedules and identify realistic energy-saving opportunities, with the readiness assessment repeated to plan the next cycle of improvement.

This progression illustrates the central design principle of the framework: each phase uses resources proportionate to a small manufacturer's existing scale, and technology is introduced to support the operator's role rather than to replace it outright.

VII. DISCUSSION: BARRIERS AND MITIGATION STRATEGIES

The barriers reported across recent literature on Industry 5.0 in SMEs — financial constraints, workforce skill gaps, limited managerial bandwidth, and low awareness — map closely to the constraints observed in the field context underlying this study. Table 3 summarises these barriers alongside mitigation strategies embedded in the proposed framework.

Barrier Category	Typical Manifestation in Small Manufacturers	Framework-Aligned Mitigation
Financial	Limited capital for automation or sensor equipment	Phase-wise investment; shared/leased equipment; cluster-based financing and government skilling or subsidy schemes
Skill and Awareness	Owners and workers unfamiliar with Industry 5.0 concepts	Phase 1 orientation; partnerships with local polytechnics and industry associations for training
Organisational	Owner-centric decisions; little spare capacity for pilots	Lightweight governance practices; small, low-risk pilot actions rather than large simultaneous

Barrier Category	Typical Manifestation in Small Manufacturers	Framework-Aligned Mitigation
		change
Technological	Legacy machines; minimal IT infrastructure	Low-cost digitalisation entry point (Phase 2) before advanced automation
Workforce Concerns	Fear of job displacement from automation	Human-centric design principle applied at every phase; upskilling paired with automation introduction

Table 3: Barriers to Industry 5.0 Adoption and Corresponding Framework Mitigations

A cluster-based approach — in which several small manufacturers in the same industrial estate jointly invest in shared training, sensing infrastructure, or advisory support — is particularly relevant in the Indian context, where industrial clusters and polytechnic institutions already provide a natural platform for such collaboration. Local technical institutions, including polytechnics, can play a facilitating role by offering readiness workshops, hosting shared demonstration equipment, and supporting workforce upskilling, thereby lowering the effective entry barrier for individual small units.

VIII. CONCLUSION AND FUTURE SCOPE

This paper has developed a phased, resource-sensitive Industry 5.0 Implementation Framework for Small Manufacturing Industries, built around five pillars — human-centricity, resilience, sustainability, technology integration, and governance — and operationalised through a four-phase maturity model supported by a readiness-assessment instrument. The framework responds directly to a gap identified in the literature: existing Industry 5.0 guidance is largely conceptual or scaled for large enterprises, leaving small manufacturers without a practical, proportionate pathway for adoption.

The proposed framework suggests that Industry 5.0 adoption need not require large upfront capital if approached as a staged journey that begins with awareness and basic digitalisation before progressing to human-centric automation and sustainability optimisation. Cluster-based collaboration and institutional support from local technical education providers are identified as practical enablers that can lower barriers for individual small units.

This study is conceptual in nature and its illustrative case is indicative rather than empirically validated. Future research should apply the readiness-assessment instrument across a sample of small manufacturing units in different sectors to test and refine the phase boundaries, quantify typical investment and payback levels for each phase, and examine how cluster-based and government-supported models affect the pace of adoption. Longitudinal studies tracking units as they progress through the four phases would also help establish causal evidence of the framework's impact on productivity, worker well-being, and sustainability outcomes.

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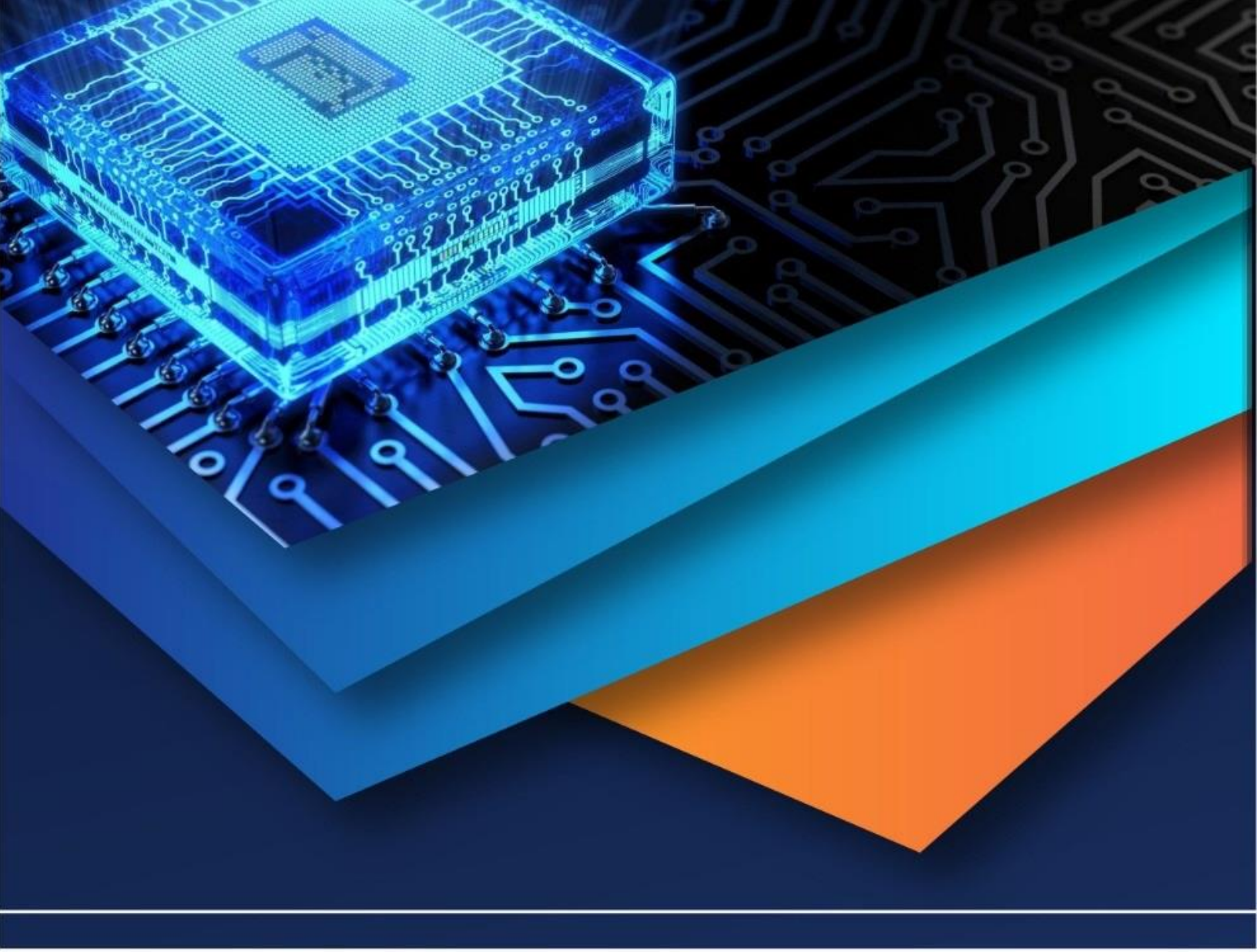

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