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Manufacturing Transformation and Skilling Evolution in Pune: A Comparative Analysis with Singapore and Germany

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Abstract

Pune’s manufacturing landscape is changing at a pace that its skilling infrastructure has not yet matched. The city has long anchored India’s automotive and engineering industries, but recent years have brought a qualitatively different kind of investment: SKF India’s ₹653 crore ‘Factory of the Future’ in Pune, LG Electronics’ deployment of AI and digital twin systems that have cut defect rates by more than 75 per cent, and Aerpace’s 180,000-square-foot advanced manufacturing facility in Chakan producing both solar panels and unmanned aerial vehicles. These are not incremental upgrades to existing processes; they represent a fundamental shift in what manufacturing in Pune demands of its workforce.

This paper examines that shift through a comparative lens, drawing on secondary data from Pune’s PM-SETU (Pradhan Mantri Skilling and Employability Transformation through Upgraded ITIs) initiative alongside published evidence from Singapore’s Advanced Manufacturing Training Academy (AMTA) and Germany’s Industry 4.0 vocational education reforms. The comparison is not intended to position global models as aspirational targets to be transplanted wholesale. Rather, it is meant to identify specific mechanisms — diagnostic frameworks, modular delivery, AI-personalised learning, peer-mentoring networks — that Pune’s current approach has not yet incorporated, and to ask whether and how they might be adapted to the Indian context.

PM-SETU is a genuine structural advance. Its hub-and-spoke ITI model, industry-led Special Purpose Vehicles (SPVs), and ₹60,000 crore five-year commitment represent a more serious response to vocational training gaps than the schemes it replaces. But comparative analysis reveals real gaps: the absence of a skills-readiness diagnostic, limited provision for employed adults who cannot leave the workforce for full-time programmes, and no equivalent of the peer-learning networks that have made Singapore’s Queen Bee model effective. These are the focus of this paper’s policy discussion.

Keywords: ***Industry 4.0, vocational skilling, manufacturing transformation, Pune, PM-SETU, smart manufacturing, comparative workforce development***

1. Introduction

The fourth industrial revolution is reconfiguring how goods are made, and consequently, who is needed to make them and with what capabilities. Cyber-physical systems, the Internet of Things, artificial intelligence, and digital simulation technologies are no longer the exclusive domain of advanced economy manufacturers; they are arriving on the shop floors of Pune’s industrial belt, carried by the investment decisions of global corporations and supported — unevenly — by state policy.

Pune is often described as India’s ‘Detroit’: a city whose manufacturing identity was shaped by Tata Motors, Mahindra & Mahindra, Bajaj Auto, and the dense supplier ecosystems they anchored. That identity has not disappeared, but it is being overlaid by something different. In February 2026, SKF India announced a ₹653 crore investment to establish what it described as a ‘lean, clean, and digitally enabled manufacturing campus’ in Pune (OEM Update, 2026). LG Electronics has deployed digital twin and AI-based quality inspection systems at its Pune facility, achieving defect reduction rates exceeding 75 per cent and cutting abnormality response times by 67 per cent (LG Electronics, 2026). Aerpace Industries has opened a 180,000-square-foot facility in Chakan for solar panel and UAV manufacturing, with a daily production target of 2,000 solar panels using bifacial TOPCon technology (Bisinfotech, 2026).

These developments raise a question that is straightforward to ask and considerably harder to answer: how must skilling systems evolve to keep pace with this manufacturing transformation? This

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paper addresses that question through three objectives. First, it characterises the current trajectory of manufacturing change in Pune, drawing on published company announcements and industry reporting. Second, it analyses the corresponding shifts in workforce skill requirements implied by that change. Third, it compares Pune's skilling policy response — centred on the PM-SETU scheme — with the models operating in Singapore and Germany, both of which have confronted similar transitions at greater institutional maturity.

The paper is based entirely on secondary data: government policy documents, corporate announcements, parliamentary records, academic literature on Industry 4.0 vocational reforms, and published reporting on manufacturing developments in Pune and the comparator countries. No primary fieldwork is claimed. The analysis is interpretive rather than statistical, aimed at identifying structural patterns and policy implications.

2. Manufacturing Transformation in Pune: Current Trajectories

2.1 Automation and AI Adoption

The most visible dimension of Pune's manufacturing transformation is the deployment of automation and artificial intelligence at the production level. LG Electronics' Pune facility provides the clearest documented case. By automating painting processes that previously depended on individual worker skill and judgement, the company doubled productivity while reducing defect rates by over 75 per cent (LG Electronics, 2026). The AI-based vision inspection system introduced for colour classification reduced the time taken for that process by 75 per cent and cut associated defects by approximately 70 per cent. Real-time equipment monitoring brought abnormality response times down by 67 per cent.

These figures are notable not only for their magnitude but for what they reveal about the nature of the change. The automation did not simply perform existing tasks faster; it shifted the locus of quality control from worker perception to algorithmic assessment, and from reactive correction to continuous monitoring. Workers were not eliminated from the process, but their function within it changed: from performing classification to supervising systems that perform it.

2.2 Digital Twin Technology and Simulation-Based Manufacturing

Digital twin technology — the creation of virtual replicas of physical production systems — represents a second, analytically distinct dimension of the transformation. LG Electronics' implementation at Pune allows management to use AI and big data analysis against the virtual model, identifying efficiency improvements and simulating interventions before they are applied to the actual production line. This capability has implications not just for process optimisation but for how decisions are made and who makes them. The value of a digital twin depends entirely on whether those who operate the physical system can interpret and act on what the virtual model shows them (LG Electronics, 2026).

SKF India's planned 'Factory of the Future' extends this logic at scale. The ₹653 crore facility, scheduled for completion by 2030, is designed to integrate 'intelligent systems, real-time insights, and energy-efficient operations' across a consolidated manufacturing campus (OEM Update, 2026). SKF has framed the investment explicitly around 'global best practices' in smart manufacturing — a framing that implies the facility will be benchmarked against, and expected to operate at comparable levels to, advanced manufacturing plants elsewhere in the world.

2.3 Diversification into Renewable Energy and Advanced Materials

The third dimension of Pune's manufacturing shift is sectoral: the city's industrial base is expanding beyond its traditional automotive core into renewable energy production and defence-adjacent technologies. Aerpace Industries' Chakan facility produces both solar panels using bifacial TOPCon technology and unmanned aerial vehicles, targeting 2,000 panels per day at full capacity (Bisinfotech, 2026). The co-location of renewable energy manufacturing with UAV production in a single advanced facility reflects a broader pattern of industrial convergence that has skill implications distinct from the automotive sector.

SKF India has also embedded sustainability as an explicit design principle in its Pune expansion, with the facility described as a 'sustainability-embedded' campus (OEM Update, 2026). This signals that environmental compliance and clean energy management are moving from optional features to expected competencies in the manufacturing workforce.

2.4 Pune as a Node in Global Manufacturing Knowledge Networks

LG Electronics' decision to use its Pune facility as a benchmark demonstration site — hosting representatives from 11 partner companies to observe automation and smart process improvements — suggests that Pune is not simply receiving manufacturing technology but is beginning to generate and transmit manufacturing knowledge (LG Electronics, 2026). This is a qualitative shift in the city's position within global value chains, and it carries implications for the sophistication of skills the workforce will be expected to demonstrate.

3. Evolving Skill Requirements for Industry 4.0 Manufacturing

3.1 From Task Execution to System Oversight

Academic literature on Industry 4.0 vocational education, including research on Germany's systemic reforms, identifies a consistent pattern of skill transition: from domain-specific technical skills toward integrated system competencies; from reactive troubleshooting toward predictive analytics; and from isolated machine operation toward networked production system management (Liu et al., 2025). These are not simply incremental extensions of existing skill sets. They require a different cognitive orientation to work — one in which understanding why a system behaves as it does is as important as being able to operate it when it behaves correctly.

The LG Electronics case illustrates this shift concretely. Where painting processes previously required manual colour classification — a skill built through extended experience — AI-based vision inspection now requires workers who can interpret system outputs, evaluate exception cases, and recognise when an algorithmic assessment needs to be questioned. The 75 per cent reduction in classification time does not remove the human from the loop; it changes what the human in that loop is expected to contribute (LG Electronics, 2026).

3.2 Data Literacy as a Foundational Competency

Real-time monitoring systems of the kind deployed at LG Electronics' Pune facility produce continuous data streams: equipment status, quality metrics, production throughput, energy consumption. Using this data effectively requires workers to read and interpret dashboards, recognise anomalous patterns, apply basic statistical process control principles, and conduct structured root-cause analysis. The 67 per cent reduction in abnormality response times reported by LG Electronics reflects both automation and enhanced human decision-making enabled by better data access and visualisation (LG Electronics, 2026). Without the second element, the first would be materially less valuable.

Data literacy, in this context, is not a specialist skill belonging exclusively to engineers or analysts. It is a shop-floor competency required across maintenance, quality, production, and logistics roles. This has significant implications for how basic vocational training is designed: data interpretation cannot be an optional module for advanced learners; it needs to be embedded in foundational trade curricula.

3.3 Cross-Functional Communication and Systems Thinking

Industry 4.0 manufacturing erodes the boundaries between traditionally separate functions. Digital twins allow production data to inform design decisions; design changes can be simulated in the virtual production environment before being implemented on the physical line. This integration requires workers who understand how their role connects to upstream and downstream processes, and who can communicate across functional boundaries in ways that traditional trade-based training did not prioritise (Liu et al., 2025).

The sustainability dimension adds a further layer. Workers in facilities like SKF India's planned Pune campus will increasingly be expected to understand energy management, material efficiency, and circular economy principles — not as background context but as operational competencies with direct relevance to daily decisions on the production floor.

4. Pune's Policy Response: The PM-SETU Initiative

4.1 Programme Architecture and Governance Design

The Government of India launched PM-SETU — Pradhan Mantri Skilling and Employability Transformation through Upgraded ITIs — in October 2025, with a ₹60,000 crore allocation over five years. The scheme's stated aim is to transform Industrial Training Institutes from 'government-owned' institutions into 'government-owned but industry-managed' ones — a formulation that signals a meaningful shift in who is responsible for ensuring training content is relevant (Ministry of Skill Development and Entrepreneurship, 2026).

Pune has been selected as one of three initial pilot districts, alongside Nagpur and Chhatrapati Sambhajinagar. The implementation follows a hub-and-spoke architecture: ITI Aundh serves as the primary hub, with ITI Girls Aundh, ITI Khed-Rajgurunagar, and ITI Mulshi functioning as spoke institutions. The structure of courses and funding is summarised in Table 1.

Table 1: PM-SETU Hub-and-Spoke Implementation — Pune District

Component	Hub — ITI Aundh	Spoke Institutions (×3)
New Courses	4	2 per spoke
Upgraded Courses	10	8 per spoke
Industry Partners	Mahindra, Tata Motors, Godrej, Fiat, Bharat Electronics	Shared across cluster
Funding Split	Central Govt: 50% | State: 33% | Industry: 17%	

Source: Ministry of Skill Development and Entrepreneurship (2026); The Times of India (2026)

4.2 Industry Governance Through Special Purpose Vehicles

A structurally significant feature of PM-SETU is the creation of Special Purpose Vehicles (SPVs) through which industry partners acquire formal governance authority over ITI operations. This is a departure from earlier approaches in which industry participation in vocational training was largely advisory. At the January 2026 industry consultation in Pune — attended by more than 40 companies from automotive, renewable energy, electronics, and FMCG sectors — the Ministry of Skill Development and Entrepreneurship stated that industry would play a 'key role in governance, curriculum alignment, and trainer upskilling' (Ministry of Skill Development and Entrepreneurship, 2026).

The SPV model addresses a longstanding structural problem in Indian vocational education: the gap between what ITIs teach and what employers need. By giving companies formal authority over curriculum design and trainee assessment, PM-SETU creates accountability mechanisms that advisory partnerships could not. Whether this translates into coherent, consistent curriculum decisions depends on the quality of the consultation processes within each SPV and on the willingness of dominant firms to accommodate the needs of the broader employer community, including smaller enterprises that may lack the capacity to engage actively in governance processes.

4.3 Infrastructure and Curriculum Modernisation

PM-SETU provides for advanced machinery, improved laboratories, digital classrooms, and updated training modules at hub institutions (The Times of India, 2026). The curriculum overhaul introduces new courses aligned with renewable energy systems, automation, and digital quality control, while existing offerings are being revised to incorporate Industry 4.0 competencies. These are substantive investments that address genuine infrastructure deficits in the ITI system.

The harder challenge is not infrastructure but instruction. New equipment in a laboratory taught by a trainer who has not worked with comparable systems in an industry setting produces limited learning outcomes. PM-SETU acknowledges trainer upskilling as a component of the scheme; the gap is in translating that acknowledgement into a structured, time-bound programme with verifiable outcomes.

5. Comparative Analysis: Singapore and Germany

5.1 Singapore's Advanced Manufacturing Training Academy (AMTA)

Singapore's approach to Industry 4.0 workforce development is coordinated through the Advanced Manufacturing Training Academy, established in 2020 under the Singapore Manufacturing Federation. The AMTA's function is explicitly anticipatory: it scans emerging Industry 4.0 developments, coordinates with SkillsFuture Singapore and sector agencies to identify in-demand skills before they become critical shortages, and works with training providers to refresh curriculum accordingly (Ministry of Education, Singapore, 2025). This is a fundamentally different operating logic from one that responds to skill gaps after they have been identified by employers on the shop floor.

Three specific mechanisms within the Singapore model are directly relevant to Pune's situation.

The Singapore Industry Readiness Index (SIRI) is a structured diagnostic tool that allows enterprises to assess their Industry 4.0 maturity across process, technology, and organisational dimensions. Its value lies not in the assessment itself but in what it enables: firms that know where they stand on the maturity spectrum can identify the specific skills their workforce needs to develop, and can prioritise training expenditure accordingly. Without an equivalent diagnostic, firms must either rely on judgement or wait for skill gaps to manifest as production problems.

The SkillsFuture Queen Bee programme has engaged leading manufacturers — including Siemens — as anchor organisations that mentor smaller enterprises in technology adoption and workforce development. Approximately 330 companies in Singapore's manufacturing sector have participated in this network (Ministry of Education, Singapore, 2025). The mechanism creates structured peer learning that governance committees cannot replicate: the knowledge transferred through this network is operational and experiential, grounded in what has been tried and what has failed, rather than in policy frameworks and curriculum documents.

Singapore Polytechnic's Advanced Manufacturing Learning Journey offers approximately 350 short upskilling programmes related to Industry 4.0, serving roughly 11,300 individuals annually (Singapore Polytechnic, 2025). These are designed for employed adults: the format acknowledges that the bulk of the workforce that needs upskilling is already in work and cannot exit for full-time programmes. Three experiential learning zones — simulating different levels of Industry 4.0 maturity from basic digitisation to fully integrated smart manufacturing — allow learners to develop practical competencies in environments calibrated to the maturity level of their own workplaces.

5.2 Germany's Dual System and Industry 4.0 Reforms

Germany's vocational education system has long been regarded as a global benchmark, primarily because its dual structure — combining workplace-based learning with school-based theoretical instruction under a legally mandated framework — produces graduates with both practical competency and conceptual understanding. The reforms undertaken to adapt this system to Industry 4.0 requirements are instructive precisely because they had to work within an established institutional structure rather than starting from a blank page, a constraint that is more analogous to India's situation than Singapore's.

Liu et al. (2025) document the core changes in Germany's Industry 4.0 vocational training reforms. The most significant is the shift from rigid, occupation-specific training standards to what the literature describes as ‘adaptable, integrated and open curriculum system frameworks.’ The practical effect is that trainers can incorporate emerging technologies into their instruction without waiting for a formal curriculum revision cycle. Given that relevant manufacturing technology now evolves faster than most curriculum review processes, this adaptability is not a peripheral feature; it is a structural requirement.

The second key element is the emphasis on ‘system and process ability’ — the capacity to understand how individual production activities connect to broader operational flows, and to reason about those connections rather than simply executing tasks (Liu et al., 2025). This is the curriculum expression of what the LG Electronics and SKF India cases suggest about actual skill requirements: what manufacturers need is not workers who can operate machines, but workers who understand systems.

The Fraunhofer IPK’s KIRA Pro project represents the digital learning dimension of Germany’s approach. The AI-based platform generates personalised learning paths for individual workers, combining online modules, in-person instruction, and workplace-embedded activities based on an assessment of the learner’s current skill profile (Fraunhofer IPK, 2024). The personalisation is functional rather than cosmetic: it reflects a recognition that workers in the same trade at the same level can have substantially different skill profiles, and that effective upskilling requires responding to those differences rather than delivering standardised content.

5.3 Comparative Assessment

Table 2 summarises the key structural differences between Pune’s PM-SETU, Singapore’s AMTA model, and Germany’s dual system across the dimensions most relevant to Industry 4.0 skilling.

Table 2: Comparative Analysis of Skilling Models

Dimension	Pune — PM-SETU	Singapore — AMTA	Germany — Dual System
Governance	Industry SPVs at ITI level	Centralised coordination + Queen Bee companies	Tripartite: employers, unions, government
Digital Infrastructure	Hub-and-spoke physical ITIs	SIRI diagnostic + experiential learning zones	AI-personalised platform (KIRA Pro)
Curriculum Model	New and upgraded courses at hub/spoke levels	~350 bite-sized modular programmes	Adaptable open framework
Employer Role	Formal SPV governance	Queen Bee peer-mentoring networks	Standard-setting via employer associations
Operating Scale	4 ITIs in Pune pilot	330+ companies in Queen Bee network	Nationwide system
Funding Model	50% central / 33% state / 17% industry	Government + employer contributions	Employer-led with state support

Source: Compiled by author from Ministry of Education Singapore (2025); Liu et al. (2025); Ministry of Skill Development and Entrepreneurship (2026); Singapore Polytechnic (2025)

The comparison reveals that Pune’s current approach is strong on governance architecture and capital investment but relatively underdeveloped in diagnostics, flexible delivery, personalised learning, and peer-learning infrastructure. These are not marginal features; they are the mechanisms through which Singapore and Germany convert investment into measurable workforce capability.

6. Discussion: Strengthening Pune’s Skilling Response

6.1 What PM-SETU Gets Right

It is worth being clear about what PM-SETU has achieved before turning to its gaps. The scheme’s hub-and-spoke architecture is a pragmatic response to the resource constraints of the Indian public vocational training system: concentrating advanced equipment and course offerings at a hub institution, while maintaining geographic reach through spoke centres, makes more efficient use of capital than attempting to equip every ITI to the same standard simultaneously.

The SPV governance model is conceptually sound. Giving industry formal authority over curriculum design and assessment — rather than treating employers as consultants to a process controlled by government — creates the structural conditions for training content to stay relevant. And the multi-sector composition of the January 2026 Pune consultation, spanning automotive, renewable energy, electronics, and FMCG, reflects a correct recognition that Industry 4.0 skills increasingly cut across sector boundaries (Ministry of Skill Development and Entrepreneurship, 2026).

6.2 Gaps Revealed by Comparative Analysis

Four gaps emerge consistently from the comparison with Singapore and Germany.

The first is the absence of a skills diagnostic framework. PM-SETU does not include a mechanism equivalent to Singapore's SIRI that would allow individual firms to assess their Industry 4.0 readiness and identify the specific skills their workforce needs to develop. Without this, training investment — both public and private — is allocated on the basis of general policy intent rather than firm-level evidence. The result is predictable: some firms invest in training for skills they already have, while others underinvest in areas where their workforce has genuine deficits.

The second gap is in flexible delivery for employed workers. PM-SETU's design is oriented primarily toward full-time ITI programmes. The majority of manufacturing workers who need upskilling are already employed: they cannot leave work for months at a time, and their employers, particularly smaller enterprises, cannot sustain extended absences. Singapore's model of approximately 350 short, modular programmes serving 11,300 employed adults annually demonstrates that an alternative delivery model is operationally feasible (Singapore Polytechnic, 2025). PM-SETU currently lacks a comparable offering.

The third gap is in personalised learning infrastructure. Germany's KIRA Pro model — AI-driven, individual-assessment-based, combining multiple delivery modes — reflects a recognition that standardised curriculum content delivers standardised outcomes, and that a workforce with varied skill profiles requires varied learning pathways (Fraunhofer IPK, 2024). Pune has no equivalent digital learning infrastructure.

The fourth gap is in peer-learning mechanisms among enterprises. Singapore's Queen Bee model creates structured knowledge transfer between advanced manufacturers and smaller firms in ways that governance committees cannot replicate. The knowledge transferred in peer networks is operational and contextual — it reflects actual experience of implementation, including what did not work. PM-SETU's SPV structure connects employers to ITIs but does not create horizontal learning channels among enterprises themselves.

6.3 Policy Recommendations

Five recommendations follow from the analysis. They are ordered by relative tractability: the first two are relatively low-cost interventions that could be piloted without major institutional change; the latter three involve longer-term structural development.

1. **Develop a Firm-Level Skills Diagnostic.** Adapt Singapore's SIRI framework to the Indian manufacturing context — specifically calibrated to the sector mix and firm-size distribution of Pune's industrial belt. A structured, time-limited assessment tool, deployable digitally by individual firms, would enable training investment to be directed at demonstrated needs rather than assumed ones. This is a relatively contained intervention that could be designed, piloted, and evaluated within a single planning cycle.
2. **Design and Fund Modular Upskilling Programmes for Employed Workers.** Complement PM-SETU's full-time ITI programmes with a structured offering of short, modular courses — accessible in evenings, weekends, and online — targeted at workers currently employed in manufacturing. This is not a peripheral supplement to the main scheme; it is the primary route through which the existing workforce, rather than future entrants to it, will be able to develop Industry 4.0 competencies.
3. **Invest in AI-Personalised Learning Platforms.** Build on the design principles of Germany's KIRA Pro — individual skill assessment, personalised learning pathway generation, multi-modal delivery — to develop a digital learning infrastructure suited to the Indian context. This is a longer-term investment, but one with potentially significant returns given the scale of India's manufacturing workforce and the heterogeneity of its skill profiles.
4. **Pilot a Queen Bee Peer-Mentoring Network in Pune.** Identify a small number of advanced manufacturers — companies like LG Electronics, SKF India, and Aerpace — and engage them as anchor organisations in a structured peer-mentoring programme for smaller enterprises in their supply chains and industrial neighbours. The mechanism requires coordination rather than large capital expenditure, and it generates exactly the kind of operational, contextual knowledge transfer that formal training programmes cannot easily replicate.
5. **Embed Sustainability Competencies in ITI Curricula.** As facilities like SKF India's planned Pune campus make sustainability an operational rather than a reporting function, the skills required to manage energy consumption, material efficiency, and circular economy principles on the production floor need to be embedded in trade-level training, not treated as specialist knowledge for graduate engineers.

7. Conclusion

Pune's manufacturing transformation is substantive and accelerating. The evidence from SKF India, LG Electronics, and Aerpace Industries is not speculative: these are announced and operational investments in AI-enabled, digitally integrated production facilities that are qualitatively different from the manufacturing environment in which the city's existing workforce was trained.

PM-SETU is the most serious policy response to this challenge that India's vocational training system has produced. Its industry-led governance model, hub-and-spoke ITI architecture, and scale of public investment represent a genuine structural advance. The question is whether those structural advances are sufficient to produce the workforce outcomes that manufacturers operating at an Industry 4.0 level actually need.

Comparative analysis with Singapore and Germany suggests they are not yet sufficient — not because the design is misconceived but because several functional elements are missing. A skills diagnostic, modular delivery for employed workers, AI-personalised learning infrastructure, and peer-learning networks among enterprises are not aspirational features of a future-state system; they are operational components of the systems that are already producing results in Singapore and Germany. Selectively adapting them to the Indian context, within the institutional framework PM-SETU has established, is the practical task ahead.

The broader implication extends beyond Pune. As manufacturing across India's industrial cities incorporates more digital integration and automation, the boundary between vocational and professional competency will continue to blur. Skilling systems that are designed around the skill requirements of the previous generation of manufacturing — however well they deliver on that design — will become binding constraints on the industrial competitiveness of the next one. Getting this transition right in Pune, where the manufacturing transformation is already visible in the investment data, would provide a model with application well beyond Maharashtra.

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