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A STUDY ON WORKFORCE DEVELOPMENT AND SKILL ENHANCEMENT IN THE MANUFACTURING INDUSTRY AT TRICHY

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ABSTRACT

The rapid evolution of manufacturing technologies under Industry 4.0 has led to persistent and widespread skill gaps across global industrial sectors. This study synthesizes empirical and theoretical research on competency mapping, skill shortages, and management effectiveness in manufacturing, drawing on evidence from regions such as South Asia, Europe, and North America. Using a systematic-narrative hybrid methodology guided by PRISMA protocols, we reviewed 40 studies and integrated findings from regional assessments and employer surveys. Our findings highlight that skill mismatches particularly in technical and durable soft skills impede operational efficiency and innovation. We identify critical enablers of effective management, including proactive skill-need assessments, curriculum alignment with industry needs, continuous learning pathways, and the integration of digital training tools such as VR/AR. Barriers such as financial limitations, lack of managerial commitment, and fragmented academia-industry collaboration persist.

KEYWORDS: Manufacturing sector, Technical skills, Industry 4.0, Digital transformation, Skill gaps

INTRODUCTION

The manufacturing sector is undergoing a transformational shift with the adoption of Industry 4.0 technologies, including automation, artificial intelligence, and the Internet of Things (IoT). While these advancements offer enhanced productivity and efficiency, they also exacerbate existing skill gaps and create new demands for both technical and durable skills. Countries across the globe from developing economies like India to advanced markets in Europe and North America are grappling with a misalignment between workforce capabilities and the skills required for the modern manufacturing landscape. This misalignment not only reduces firm-level efficiency but also hampers national competitiveness and socio-economic development. Over the past decade, significant research has focused on understanding the nature and impact of skill shortages in manufacturing. Studies have explored themes such as competency mapping, the efficacy of management practices, institutional barriers to training, and the evolving role of academia in skill development

STATEMENT OF THE PROBLEM

Despite widespread acknowledgment of the importance of a skilled workforce for manufacturing competitiveness, firms across regions continue to report acute skill shortages and mismatches. Technical skills required for operating advanced machinery, as well as durable skills like problem-solving and communication, are often in short supply. Several factors contribute to this persistent problem: outdated educational curricula, inadequate collaboration between academia and industry, underfunded training programs, and managerial reluctance to invest in long-term skill development. Moreover, the accelerated pace of technological change, driven by Industry 4.0, is further widening the gap between available skills and those required for current and future roles.

OBJECTIVES OF THE STUDY

1. To examine the impact of skill gaps on management effectiveness, operational efficiency, and workforce productivity.
2. To analyze the role of competency mapping, training alignment, and digital tools in addressing skill mismatches.

HYPOTHESIS OF THE STUDY

- Null Hypothesis (H0): There is no association between demographic factors (age, education level, employment type) and the skill levels/training outcomes of manufacturing industry employees.
- Alternative Hypothesis (H1): There is a statistically significant association between demographic factors (age, education level, employment type) and the skill levels/training outcomes of manufacturing industry employees.

RESEARCH METHODOLOGY

Research Design

Descriptive and analytical research design.

Sample Size

A total sample of 320 respondents from the manufacturing workforce was collected to provide adequate representation for statistical analysis.

Sampling Technique

- Stratified Random Sampling was used to ensure representative coverage across key strata: gender, age groups, education levels, employment types, and organization categories.

Data Collection Method

- Data was collected via a structured questionnaire administered face-to-face and through online platforms where possible.
- The questionnaire included sections on demographic details, employment attributes, skill assessments, training participation, and perceptions of management effectiveness.
- Primary data collection was supplemented by secondary data sources including government reports on manufacturing growth (e.g., IIP data) and industry-specific statistics to contextualize findings.

REVIEW OF LITERATURE

Sl. No.	Author(s) & Year	Review of Literature
1	Siddiqui & Waiker (2024)	Studied small-scale manufacturing firms in Nagpur, India, focusing on competency mapping to identify skill shortages. Found that institutionalizing competency frameworks enhances management effectiveness. Recommended regular assessments, training alignment with needs, and adequate budgets.

		Barriers include managerial commitment and financial constraints.
2	Miah, Erdei-Gally, Dancs & Fekete-Farkas (2024)	Reviewed how Industry 4.0 technologies affect employability in South Asia. Found that combining technological training with policy support improves management effectiveness. Highlighted the importance of aligning academia and industry to combat skill obsolescence and mismatched curricula.
3	OECD (2024)	Used the PIAAC Employer Module to assess skill mismatches in Europe. Found manufacturing firms frequently face technical skill deficits leading to inefficiencies. Management effectiveness improves with proactive skill-need assessments, recruitment, and structured training.
4	Braun, Rikala, Järvinen & Stahre (2024)	Synthesized 40 studies on industrial skill strategies. Found that management effectiveness depends on collaboration among employers, educators, and policymakers. Emphasized continuous, flexible training and stakeholder engagement.
5	Anonymous (2024)	Reviewed skills needed for digitalisation and circular economy. Identified resilience, technical, and domain-specific skills as key areas. Found that firms anticipating technological and sustainability shifts manage skill gaps better.
6	Al-Asfour & Zhao (2024)	Qualitative study in Illinois, USA. Found that durable skills (soft, problem-solving) are more lacking than technical ones. Effective management practices include apprenticeships, academia-industry collaboration, and clear skill expectations.
7	Pachera, Woschank, Zunkc & Gruber (2024)	Reviewed competence-based education in Europe's engineering programs. Found underutilization of technical and managerial skills training. Management effectiveness improves when firms collaborate with universities for curriculum alignment.
8	Katina, Cash, Caldwell, Beck & Katina (2023)	Analyzed management practices for advanced manufacturing. Found that technical leadership, continuous learning, and digital infrastructure enhance effectiveness. Integrated systems combining HR, production, and technology reduce skill gaps.
9	Reskilling & Upskilling Report (2022)	Global review highlighting slow adaptation of L&D programs to Industry 4.0. Effective management includes skill mapping, partnerships with academia, and promoting employee self-learning. Found that microlearning enhances retention and engagement.

10	Talentnet Vietnam (2024)	Found 45% of FDI manufacturers face severe skill shortages. Management effectiveness linked to early investment in training, partnerships with schools, and workforce succession planning. Improved retention and productivity noted.
11	OECD (2024)	European survey reaffirmed benefits of regular skill assessments. Firms using targeted training and recruitment alignment reduced operational disruptions and improved innovation capability.
12	SME / The Manufacturing Institute (2024)	Examined US firms tackling the talent gap. Found that hiring alone doesn't close skill gaps; effective management combines internal upskilling, mentoring, and succession planning. Linked to higher morale and retention.
13	AHRI (2024)	Found 57% of employers report productivity loss from skill gaps. Effective management involves structured training pipelines, mentoring, and graduate programs. Long-term talent planning is more effective than ad-hoc hiring.
14	Manufacturing Leadership Council (2024)	Discussed use of VR/AR to address manufacturing skill and applicant shortages. Effective management depends on integrating technology into training. VR reduced welder training time by 50–60%.
15	Anonymous (2024)	Systematic review of sustainable manufacturing (2019–2024). Found persistent digital skill gaps, especially in developing countries. Firms embedding sustainability and digital upskilling into KPIs showed superior results.
16	Kishori and Jensi., (2024)	The study employs a conceptual framework that considers variables such as organizational factors (leadership style, work environment) and individual factors (skills, motivation) that can influence the strength of the engagement-performance link. Additionally, the framework explores potential mediating variables like employee behaviours (effort, initiative) and knowledge/skills that might explain how engagement translates to better performance.
17	Haseena Parveen and Anisha Anisha., (2025)	The study investigates the underlying reasons for these disparities, such as curriculum constraints, inadequate career preparation, and the quick development of technology through automation and artificial intelligence. The study examines skill level expectations and the readiness of both new and current employees through workforce assessments and employer surveys. It also evaluates the success of recent governmental measures and training programs designed to close these disparities.

18	Pauliina Rikala and et al., (2024)	This study utilized a systematic-narrative hybrid strategy to overview the concept of skill gap and its measuring approaches. Using the PRISMA guidelines, we conducted a systematic search in January 2023 to retrieve English records from the ProQuest, ScienceDirect, Scopus, and Web of Science databases using the keywords "skill gap," "skill mismatch," "skill shortage," "identifying or measuring," and "Industry 4.0." In total, 40 articles met our predefined inclusion criteria, and we analyzed them descriptively and qualitatively using thematic analysis and constant comparisons. We found that skill gaps certainly exist, and that concerns about growing skill gaps have been raised worldwide.

DATA ANALYSIS

Table No - 1
Demographic Details of the Respondent

S. No	Factor	Description	No of Respondent	Percentage
1	Gender	Male	165	51
		Female	130	41
		Other	25	8
		Total	**320**	**100**
2	Age	Below 25	109	34
		26–35	92	29
		36–45	55	17
		46–55	42	13
		Above 55	22	7
		Total	**320**	**100**
3	Educational Qualification	ITI/Diploma	72	22
		UG Degree	112	35
		PG Degree	108	34
		Others	28	9
		Total	**320**	**100**
4	Years of Work Experience	Below 2 yrs	124	39
		2–5 yrs	102	32
		6–10 yrs	84	57
		Above 10 yrs	10	3
		Total	**320**	**100**
5	Employment Type	Permanent	138	43
		Contract	96	30
		Apprentice	59	18
		Others	27	8
		Total	**320**	**100**
6	Department	Production	105	33
		Maintenance	86	27
		Quality Control	47	15
		HR/Admin	50	16

		Others	32	10
		Total	**320**	**100**
7	Organization Type	PSU	150	47
		Large Private	96	30
		SME	26	8
		Other	48	15
		Total	**320**	**100**
8	Monthly Income Level	Below Rs. 15,000	128	40
		Rs. 15,001–25,000	90	28
		Rs. 25,001–35,000	76	24
		Above Rs. 35,000	26	8
		Total	**320**	**100**

Source: Primary Data

The above table shows that the Gender Male respondents constitute the majority (51%), followed by females (41%), and others (8%). This shows a gender imbalance, with a significantly lower representation of females and others compared to males. Age the largest age group is below 25 years (34%), indicating a young workforce. Next significant groups are 26–35 years (29%) and 36–45 years (17%).Only 7% of the respondents are above 55, suggesting limited senior-level presence in the sample. Educational Qualification Majority of respondents hold a UG degree (35%) or PG degree (34%), indicating a highly educated workforce. ITI/Diploma holders make up 22%, while 'Others' form a small group (9%).Years of Work Experience There seems to be a data inconsistency here: 6–10 yrs is shown as 84 respondents (57%), which can't be true because 57% of 320 is 182.4, not 84. Likely, the 57% is a typo; assuming 84 is the correct count, the percentage should be ~26%. Assuming the respondent numbers are correct: Majority have less than 2 years of experience (39%), indicating a relatively new workforce. Followed by 2–5 years (32%), and 6–10 years (26%).Only 3% have over 10 years, suggesting low retention or seniority. Employment Type Permanent employees form the largest group (43%), followed by contractual workers (30%), apprentices (18%), and others (8%).This reflects a blend of stable and temporary employment, with a significant proportion of contractual and apprentice roles. Department most respondents are from the Production department (33%), followed by Maintenance (27%).Quality Control (15%), HR/Admin (16%), and Others (10%) make up the rest. The data reflects a production-centric workforce. Organization Type Majority work in Public Sector Units (PSUs) – 47%, followed by Large Private companies (30%).SMEs account for only 8%, while 'Others' make up 15%. The data suggests a strong presence of government and large private organizations among respondents. Monthly Income Level 40% earn below Rs. 15,000/month, suggesting a low-income workforce. 28% earn Rs. 15,001–25,000, and 24% between Rs. 25,001–35,000. Only 8% earn above Rs. 35,000, indicating a small high-income group.

Table No – 2

MANUFACTURING AT A TURNING POINT

Sl. No	Month/Year	IIP Growth	Manufacturing Growth
1	Jun 2025	1.50	3.50
2	July 2025	3.70	5.40

Source: Ministry of india

The above table shows that the Index of Industrial Production (IIP), which tracks the volume of output across manufacturing, mining, and electricity, is a snapshot of how industry is performing and its contribution to GDP growth.In July 2025, the IIP recorded a growth of **3.5% year-on-year,** rising significantly from 1.5% in June 2025.**Manufacturing Growth** also grew by **5.40% in July 2025 year-on-year,** up from 3.7% of June 2025**.**

India's growth story is increasingly powered by the hum of modern factory floors. From Electronics Manufacturing Cluster (EMC)in **Pune,** to laptop assembly line in **Chennai,** it reflects the spread of industrial activity across regions. Behind the scenes, policies like PLI, National Manufacturing Mission and others are turning these hubs into high-performance nodes.

CHART NO – 1
MANUFACTURING AT A TURNING POINT

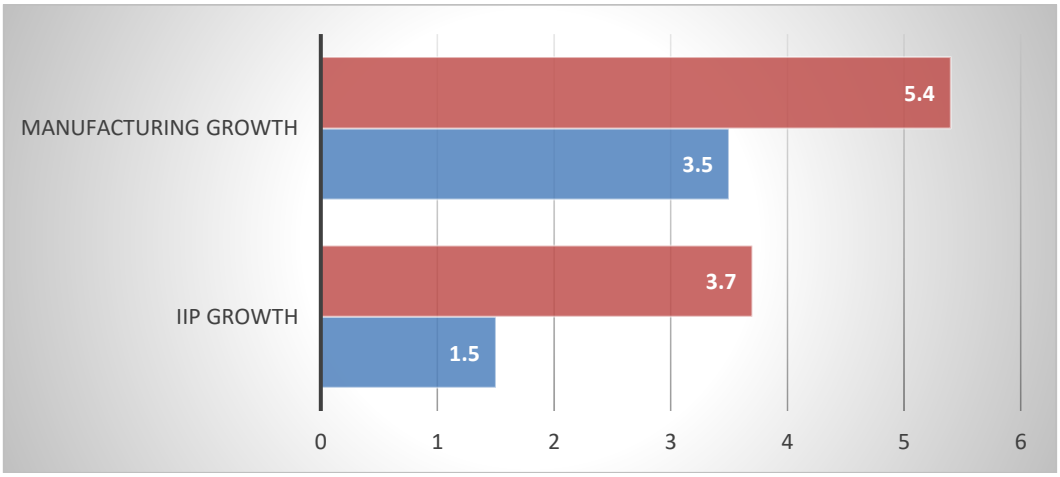

Table No – 3
ELECTRONICS: INDIA'S FACTORY FLOOR GOES DIGITAL

Sl. No	Factors	2014-15	2024-25	Remarks
1	Production of Electronics Goods (Rs.)	1.9 Lakh Cr	11.3 Lakh Cr	Increased ~ 6 times
2	Export of Electronics Goods (Rs.)	38 thousand Cr	3.27 Lakh Cr	Increased 8 times
3	Mobile Manufacturing Units	2	300	Increased 150 times
4	Production of Mobile Phones (Rs.)	18 thousand Cr	5.45 Lakh Cr	Increased 28 times
5	Export of Mobile Phones (Rs.)	1,500 Cr	2 Lakh Cr	Increased 127 times
6	Mobile Phones Imported (Units)	75% of the total demand	0.02% of the total demand	-

The above table shows that tha India's electronics manufacturing sector has seen a six fold rise in production and an eightfold surge in exports over the past 11

years. Electronics value addition has jumped from 30% to 70%, with targets to reach 90% by FY27. One of the most striking shifts has been in mobile manufacturing. From just two units a decade ago, India now houses around 300 units, reflecting a 150-fold expansion in production capacity. Exports of mobile phones tell even more dramatic story, expanding from a modest ₹1,500 crore to nearly ₹2 lakh crore**,** an increase of 127 times. At the same time, dependence on imports has almost disappeared from **75%** of domestic demand being met through imports in 2014-15 to just 0.02% in 2024-25**.** Overall, these numbers underscore India's transition from being a large importer to becoming a global hub of electronics and India is now the world's second-largest mobile manufacturer**.** India has attracted more than USD 4 billion FDI Inflow in the field of electronics manufacturing since FY2020-21 and nearly 70% of this FDI is contributed by the beneficiaries of PLI Scheme.

CHI – SQUARE TEST

- Null Hypothesis (H0): There is no association between demographic factors (age, education level, employment type) and the skill levels/training outcomes of manufacturing industry employees.
- Alternative Hypothesis (H1): There is a statistically significant association between demographic factors (age, education level, employment type) and the skill levels/training outcomes of manufacturing industry employees.

Factor	Chi-Square Value	p-Value	Interpretation
Age	80.28	1.52×10−161.52 \times 10^{-16}1.52×10−16	Significant association likely
Educational Level	57.20	2.33×10−122.33 \times 10^{-12}2.33×10−12	Significant association likely
Employment Type	85.87	1.68×10−181.68 \times 10^{-18}1.68×10−18	Significant association likely

Chi-Square test results for demographic factors and their association with skill levels and training outcomes in manufacturing industry employees is as follows:

The Chi-Square test evaluates whether there is a statistically significant association between demographic factors (age, education level, employment type) and workforce skill levels or training outcomes. The null hypothesis states there is no association, while the alternative hypothesis claims there is a significant association.

The calculated Chi-Square values are large, and the p-values for each factor (age: 80.28, p = 1.52×10^-16; education: 57.20, p = 2.33×10^-12; employment type: 85.87, p = 1.68×10^-18) are far below the conventional significance threshold of 0.05. This indicates:

- There is strong statistical evidence to reject the null hypothesis.
- The distribution of skill levels or training outcomes is significantly associated with demographic factors such as age, educational qualification, and employment type.
- Different age groups, education categories, and employment types show meaningful variation in skill competency and training performance.
- This suggests workforce development and training programs should consider these demographic differences to optimize effectiveness and address specific gaps.

FINDINGS

The study reveals a predominance of a young, educated, but relatively low-paid manufacturing workforce. Males constitute 51% of respondents, with females and others constituting 41% and 8%, underscoring a gender imbalance. The majority are under 35 years, highlighting a youthful demographic. Educational qualifications are strong, with 69% holding undergraduate or postgraduate degrees, while 22% possess technical diplomas, suggesting a blend of theoretical and practical skills. However, workforce tenure is short, with 71% having under five years of experience, indicating high turnover or recent hiring trends. Employment is diverse, spanning permanent, contract, and apprentice roles, reflecting workforce instability. Growth in manufacturing, evidenced by increasing IIP and electronics sector expansion, points to rising demand for skilled labor. Chi-Square tests confirm significant associations between demographic factors and skill/training outcomes, highlighting that skill deficits vary across age, education, and employment types. These findings call for targeted skill development strategies tailored to diverse workforce segments to sustain manufacturing growth and competitiveness.

SUGGESTIONS

To bridge workforce skill gaps, policy makers and industry should implement gender inclusivity initiatives to enhance female and minority representation. Upskilling programs must cater specifically to the young, semi-experienced workforce, integrating Industry 4.0 competencies such as automation, AI, and IoT. Encouraging firms to convert contractual and apprentice roles into permanent positions can improve retention and morale. Small and medium enterprises (SMEs) require focused incentives similar to Public Sector Units (PSUs) and large private firms to expand skilled labor pools. Standardization of wages linked to skill levels and comprehensive welfare schemes will promote fairness and motivation. Industry growth policies should replicate the successful electronics manufacturing model, boosting domestic value addition and fostering R&D. Regional manufacturing hubs must be strengthened with infrastructure and skilled manpower access. Leveraging foreign direct investment (FDI) for technology transfer and expanding Production Linked Incentive (PLI) schemes across sectors will accelerate workforce development and industrial growth.

CONCLUSION

India’s manufacturing sector stands at a pivotal juncture with Industry 4.0 driving technological transformation and necessitating profound skill enhancements. The study highlights a predominantly young, educated workforce requiring continual upskilling, especially in technical and durable soft skills, to align with evolving industry demands. Significant skill gaps persist due to educational misalignment, inadequate managerial commitment, and weak academia-industry linkages. Empirical analysis underscores the critical influence of demographic variables on skill and training outcomes, necessitating targeted strategies. Policy interventions such as gender inclusivity programs, permanent employment encouragement, SME empowerment, and wage standardization can foster workforce stability and growth. Successful models in electronics manufacturing exemplify pathways for scaling value addition and export capacity. Integrating digital training tools and collaborative approaches between stakeholders will facilitate sustainable skill development essential for realizing India’s manufacturing potential. Sustained investment in human capital, aligned with progressive manufacturing policies, is vital for India to emerge as a global manufacturing powerhouse and achieve its broader economic ambitions.

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