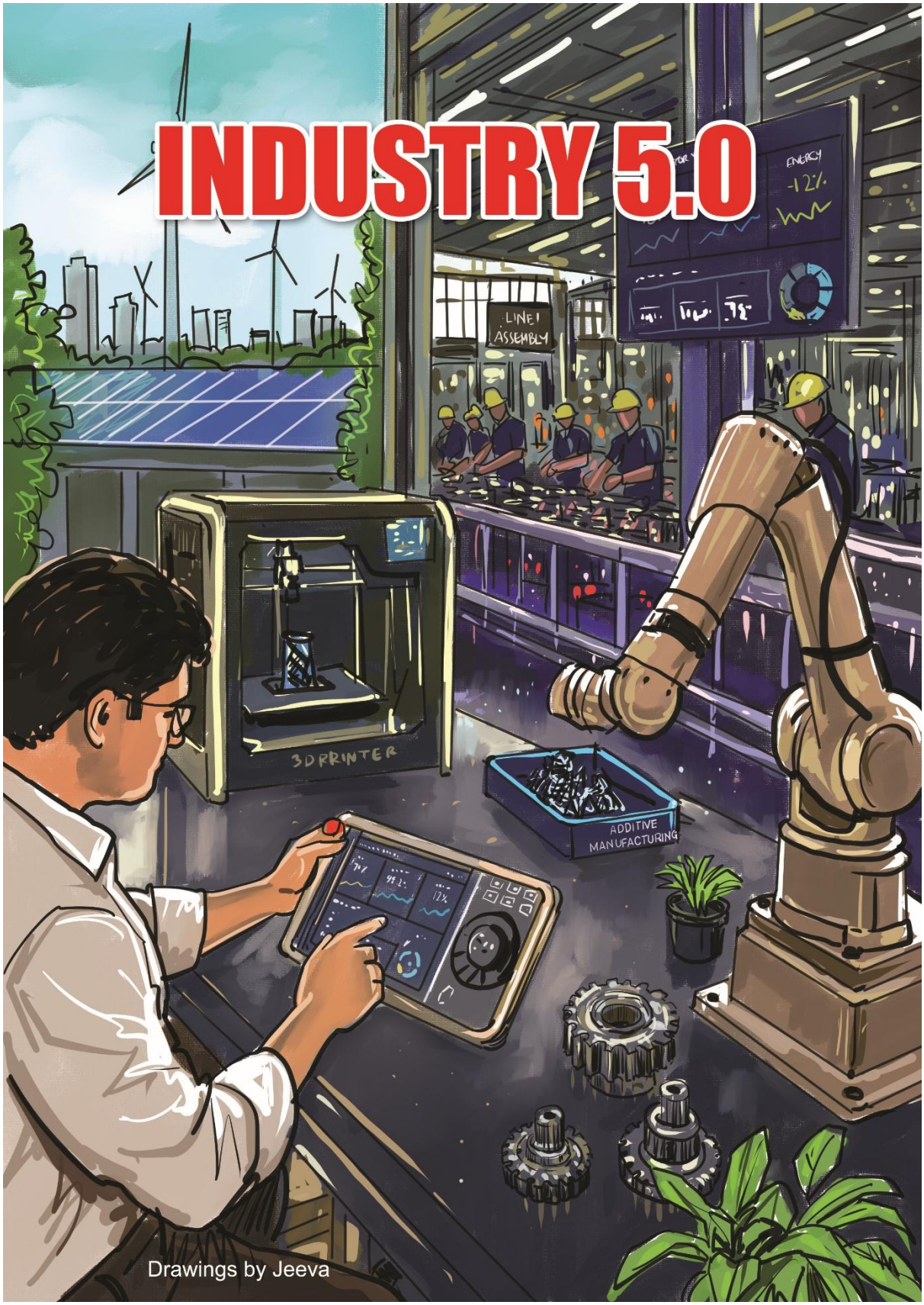

INDUSTRY 5.0
ENERGY
-12%
LINE1
ASSEMBLY
3DRRINTER
ADDITIVE
MANUFACTURING
Drawings by Jeeva

INDUSTRY 5.0

A Growth Strategy for MSMEs

Sambath Parthasarathy
&
Mythily Parthasarathy

“ Disruptive technologies typically enable new markets to emerge ”

- *Clayton M Christensen, in Innovator’s Dilemma*

Research Report – SSS-2026-I5.0-001

Tamil Nadu, India

May 2026

Contents

List of Tables 5
List of Figures 6
Report Revision history 7
Declaration 8
Acknowledgements to Industry thought-leaders. 9
1 Executive Summary 12
2 Industry 5.0 and MSME Glossary 14
3 Who can benefit from this research report? 18
4 Introduction 19
5 Literature Survey 20
6 Objective of this Research 21
7 The Scope of the Research 22
8 Research Methodology 24
9 Data Sources 25
10 Industry 5.0 26
10.1 Comparison of Industry 4.0 and 5.0 27
10.2 Industry 5.0 Reference architecture- RAMI 5.0 31
10.3 Industry 5.0 Benefits to MSMEs 32
10.4 Industry 5.0 Solutions 34
10.5 Engineering Institutes in Tamil Nadu working in related area 40
10.6 Centre of Excellence(CoE), and Research Centres in TN 41
10.7 Other Key Industry 5.0 stakeholders 42
10.8 Compliance and Industry 5.0 43
10.9 Industry 5.0 Core themes and Best Practices 44
11 Mapping industry specific processes to Industry 5.0 Technology solution component ... 47
12 Industry 5.0 Adoption Challenges faced by MSME 52
13 Upskilling 63
14 MSME cluster – Engineering Colleges-Innovation Hubs 65
15 Actionable Recommendations 66
15.1 Recommendations 66
16 Planned Future Work 82

Wave 1/Phase I 82
Wave 1/Phase II 82
Wave 2/Phase I 82
Wave 2/Phase II 82
17 Key Take-aways 83
18 References 84
Annexure – A1 87
Interview Questionnaire 87
Annexure – A2 88
Government's effort to strengthen the MSMEs 88
Annexure – A3 90
Industry 5.0 sustainability skills trends 90
Sustainability skills 90
Annexure – A4 92
Classification of enterprises 92
Annexure – A5 (formatting of Notes in progress) 93
Minutes of the meeting / Interview Notes 93
Interview 1, Minutes of the meeting, 16-01-2026, 3 PM, Prestige Bella Vista 93
Interview 2, Minutes of meeting, Tuesday and Wednesday, 20 and 21 Jan 2026, 3:00 PM 94
Interview 7, Ashish Khushu Minutes of the meeting, 2-2-2026, 2.30 PM, Gmeet 96
Interview 8, Satyanarayana Venkatraman Minutes of the meeting, 3-2-2026, 10.30 AM, Online 97
Interview 9, Dr. Prakash, Minutes of the meeting, 5-2-2026, 10.30 AM, Eswari Engineering college, ... 98
Interview 11, Minutes of the meeting, 6-2-2026, 3.00 PM, IIT Madras 100
Interview 12, Ms. Shobana Ravi ,Minutes of the meeting, 12-2-2026, 4.00 PM, TAFFE 102
Interview 13, Minutes of the meeting Friday, 27 Feb 2026 104
Interview 14, of the meeting, 20-3-2026, 11.00 PM, Online 104
Interview 15, Minutes of the meeting, 31-3-2026, 12.00 PM, Online 106
Interview 16 Meeting Transcript 108
Interview 17 Minutes of the meeting held with Mr. G. V. Manimaran 114

Interview 18 Minutes 116
Annexure – A6 – Industry 4.0/5.0 Public domain Case Studies 120
Case Study 1 120
Case Study 2 121
Case Study 3 122
Case Study 4: 123
Case Study 5 124
Case Study 6 124
Case Study 7 125
Case Study 8 126
Case Study 9 127
Case Study 10 128
Annexure – A7 130
Sample Industrial Problems Requiring Solutions 130
Annexure – A8 131
Description, References and Institutes involved in Industry 5.0 solutions mentioned in Section 11 131
Appendix A9: 139
Appendix A10: India AI Mission 140
Appendix A11: Additional Notes on Recommendations 141
Appendix 12: Layered Strategic recommendations for Cybersecure-MSMEs 143

List of Tables

Table No.	Title	Page no.
1	Report Revision history	7
2	Acknowledgements	9
3	Industry 5.0 and MSME Glossary	13
4	Industry Sectors of interest	20
5	Supplier-OEM relationship	21
6	Comparison of Industry 4.0 and 5.0	25
7	Sample 3D printers	32
8	Mapping Industry processes to Industry 5.0 solutions	45
9	Challenges	50
10	Actionable Recommendations.	64
11	Interview Questions	85

List of Figures

Figure No.	Title	Page no.
1	Research methodology	22
2	Evolution of Industrial Revolutions	24
3	Automotive Technologies and solution instances	27
4	Robots' installations in 2025	27
5	Industry 5.0 Reference architecture	28
6	Sum of initial battery capacity by State	28
7	Sum of initial battery capacity & Sum of full battery capacity by State	29
8	Stan Shih's Smile-curve-of-sterilization	30
9	1. % firms offering formal training, 4. %firms introduced process innovation 5. % firms that spend on R&D	31
10 a	Evolution leading to cobots	32
10 b	ABB Cobot Model – Collaborative Robot – GOFA – 15000	32
11a	Predictive maintenance solution	33
11b	Manufacturing digital twins flow	35
12a	Industry 5.0 growth indicators – Additive Manufacturing Market growth	36
12b	Sample Industry 5.0 Roadmap	36
13	Compliance is critical for exports	41
14	Difference in thematic goals between last three Industrial revolutions	42
15	Industry 5.0 growth indicators – Annual Robots installation	43
16	World Bank Enterprise Surveys 2022	60
17	India's ranking in Global Innovation Index 2025	60
18	Upskilling sector specific skills (Image courtesy NSDM[27])	61
19	Skill Development Program	62
20	Cluster innovation hubs	63
21	Sustainability skill Growth Vs Country	89
22	Energy efficiency skill Growth vs Country	90
23	Machine learning for machines in tyre factory	119
24	HMG's test-data-driven MBSE for authoring test models for virtual development	122
25	http://bit.ly/4tzcMGM	122
26	https://www.bmwgroup.com/en/news/general/2023/aiqx.html	123
27	Reactor installed at CETP, Tiruppur	123
28	India AI mission	138

Report Revision history

Version	Revision history	Person	Date
V8	First-cut review & feedback Mention Covid, no Finance & policy discussion, robotic growth Reviewed Roadmap & asked to include upskilling every quarter	Mythily/Mukundan	12-04-2026
V9	Formatting by Roger – placed interviews in boxes	Roger	14-04-2026
V10	Incorporated Robotic growth, smiling curve, roadmap feedback	Sambath	14-04-2026
V11	Properly extract organize challenges from interview notes	Sambath	15-04-2026
V14	Added publicly available ZLD real life implementation. Added more recommendations.	Sambath	24-04-2026
V14	Finalizing Recommendations, added cover photo	Sambath	27-04-2026
V15	Ordering Sections	Sambath	01-05-2026
V16	Added Cover design, added three more case studies, added Cyber Security recommendation	Sambath	02-05-2026
V19	Corrections, added interview notes, update cover design, improved Key Takeaways	Sambath/Mahesh	11-05-2026

Table 1: Report Revision history

Declaration

The recommendations and write-up provided in this report are human generated based on point-of-views of interviewees. The conclusions and recommendations presented in this report are authors views guided by the experienced technology leaders in this domain. The minutes of the interviews have been recorded as the proof of human-generated content.

We used generative AI only for literature survey, and information gathering.

Wherever we are referring to third-party data, we have duly acknowledged the source. In Annexure – A6, Case Studies presented are Industry 4.0/5.0 public domain Case Studies. The source of the information and authors have been duly acknowledged

Also, we have placed some more publicly available information in Appendix.

Acknowledgements to Industry thought-leaders.

We are very thankful to all the Academia/Industry/Technology/Business thought-leaders listed below. We sincerely appreciate the time they allotted for interviews, interest and involvement they showed in this research. **The authentic source of the information reported in this report has come from the wisdom of these thought-leaders**. Gratitude to them. Without them sharing their wisdom, this research would not have been possible. Minutes of the meeting of all interviews have been attached as Appendix.

S.No	Name	Designation/Experience (MSME cluster)	Date/Time	Interviewer
1	Mr. Srinivasa Raghavan	40+ years' experience in Automotive technology, in Simpson, Bosch, and Delphi TVS	Friday, 16 Jan 2026, 2.30 PM	Sambath & Mythily
2	Mr. Raghavan Venkatesan	30+ years ex TVS R&D, Hosur, Krishnagiri	10 AM, Wednesday, 21st Jan 2026	Sambath.
3	Mr. Rajieve	Original Match Factory, Sattur, Virudhunagar	10 AM, Friday, 10th April 2026	Sambath
4	Mr. Ravindra & Mr. Dinesh	MACS, Sattur, Virudhunagar	11 AM, Friday, 10th April 2026	Sambath
5	Meenakshi Sundaram	CTO, Amalgamation, Mount Road, Chennai	Tuesday and Wednesday, 20 and 21 Jan 2026, 3:00 PM.	Dr. Sundar, Mythili & Sambath.
6	Ashish Khushu	CTO, LTTS, Bangalore	Monday, 2 Feb 2026, 2:00 PM.	Murali, Mythili & Sambath.
7	Dr. Sathyanarayanan Venkatraman	Kyndrl, Chennai	3-2-2026, 10.30 PM	Murali & Sambath
8	Dr Prakash	Research Centre, Easwari Engineering college, Chennai/Tiruvallur	5-2-2026, 10.30 AM,	Vittal, Mythily & Sambath
9	Shankar Venugopal	CTO, M&M, Coimbatore/ Bangalore	Friday, 30 Jan 2026, 6:00 PM.	Murali, Sunil David, Kaushik, Mythili, Sambath & Muthuswamy
10	Prof R.K.Amit	DOMS, IIT Madras	Friday, 6-2-2026, 3.00-4.00 PM, IIT Madras	Mythili, & Sambath

11	Shobana Ravi	President, Infotech, Innovation & Learning, TAFE, (Chennai)	Tuesday, 12-2-2026, 4.00-5:30pm PM, TAFE office, Chennai	Vaithy, Mythily, & Sambath
12	Dr. Aiyappan Ramamurthy	Services Director, Siemens Digital Industries Software, Chennai	Friday, 27 Feb 2026, 4:30 – 5:30pm	Dr. Sundar, Sambath, Mythily & Muthuswamy
13	Mr Rajesh	Auto Component Manufacturer Association (ACMA)	Wednesday, 18th March 2026, 5-6pm	Sambath & Mythily
14	Mr Ramachandran	Practice Leader – Engineering, R&D, Manufacturing, Automotive at HFS Research.	Friday, 20th March 2026, 11 am – 12noon	Sambath, Vaithy & Mythily
15	Dr Karthikeyan Mounaguruswamy	President at CODISSIA, MD, Sukshma Dynamics, (Coimbatore)	Tuesday, 31st March 2026, 12-1.00 pm	Sambath, Jai Sri Ram & Mythily
16	Dr Raghavendra Prasad	Senior Consultant, Alumnus IIT Madras, IIM Ahmedabad	Thursday, 2nd April 2026, 8.30 -9.30 PM	Sambath, Jaisri Raju Sriram
17	G. V. Manimaran	Director at Sasvitha Home Finance Pvt. Ltd.Chennai		
18	Dr. E. Bhaskaran	Joint Director, T.N Startup & Innovation mission	Wed, 15th April 2026,	Mythily, Sambath
19	Mr. Sankar	TEAMA, Tirupur	Wednesday, 8th April 2026, 7.30 -8.30 PM	
20	Dr Apoorva Haree	FICCI, FLO, Senior Vice Chairperson, Executive Director, Rajalakshmi Institutions (Kanchipuram)	Online, Thu, 16th April 2026	Mythily, Sambath
21	Prof. V. Kamakoti	Director, IIT Madras	Saturday, 25th April 2026	Mythily, Sundar, Vittal, Muthuswamy, Sambath
22	Mr. C.K. Mohan	Past President, TANSTIA		Mythily, Sambath

Table 2: Acknowledgements

Mr. Venkatesan, Mr. Meenakshisundaram, Mr. Mukundan and Mr Ramachandran reviewed certain parts of the report. Thanks to them for sharing their valuable feedback.

Our special Thanks and gratitude to Dr. Sundar, Mr. Vittal Raj, Mr. Muthuswamy M.R, Mr. Vaithyanathan Chandramouli, Dr. Murali Meenakshisundaram, R. Koushik, Mr. Sirish and Ms. Jai Sri Sriram for participating in some interviews. Dr Sumitha Vibhu, Mr Vittal Raj, Mr. Venkatesan, and Dr. Raghavendra Prasad for sharing some important inputs. They joined interviews and some of them helped craft some recommendations. Thanks to Roger Christopher for nicely formatting the report. Thanks to Mr. Jeeva for the artwork. Thanks to Mahesh.

We thank the Enterprise Analysis Unit of the Development Economics Global Indicators Group of the World Bank for the data.

1 Executive Summary

- The vision of Viksit Bharat, a stable democracy, a growing middle class, strong English-language proficiency, and an expanding AI-skilled workforce make India—and particularly Tamil Nadu—highly attractive destinations for MSMEs to flourish. In such a favourable ecosystem, MSMEs now require further impetus through Industry 5.0 to accelerate their growth, competitiveness, and value creation.

- Evolving further on the past successful industrial revolutions, Industry 5.0 stands tall as the guiding light for all Industries for achieving higher profitability, productivity, operational efficiency

- Industry 5.0 provides a strategic framework for a responsible technology strategy to achieve an accelerated business growth in the global market.

- In addition to the state of the art technologies, like Artificial Intelligence(AI), Industrial Internet of Things (IIoT), Cobots, Additive manufacturing, Industry 5.0 includes sustainability, and Resilience. Thus, Industry 5.0 offers powerful capabilities like environmental responsibility, workforce-well-being, and supply-chain resilience.

- All manufacturing focused countries have realized the undisputed fact that the MSME sector has been one of the key driving forces behind their economic growth and employment generation.

- We believe that by adopting Industry 5.0, MSMEs can further accelerate the growth.

- This research examines the challenges faced by MSMEs in adopting Industry 5.0 and provides recommendations to mitigate them.

- Authors strongly believe that in addition to solving operational manufacturing challenges, Industry 5.0 has the potential to move the MSMEs up in the value-chain. Just by doing manufacturing, MSMEs profit margin will remain very thin. By adding value to the product life cycle through innovation, personalized design and path-breaking R&D, the profitability can be increased.

2 Industry 5.0 and MSME Glossary

No	Terminology	Description
1	Industry Sectors	Broad classifications (e.g., Automobile, Textile) based on the type of product or process. (e.g., the automobile sector includes component manufacturing, car assembly, etc.).
2	Industry Segments	These are narrower subsets or specific niches *within* an industry or a market. include "Electric Vehicle (EV) Segment" or "Luxury SUV Segment."
3	Mass customization	Mass customization is a manufacturing and business approach that combines the efficiency of mass production with the flexibility of customization, allowing companies to produce goods tailored to customer needs
4	Mass personalization	Mass personalization is leveraging data analytics, AI, and advanced manufacturing (e.g., 3D printing) to produce uniquely tailored goods for individual customers at scale
5	Smart Factory	a smart factory has interoperable systems, multi-scale dynamic modelling and simulation, intelligent automation, strong cyber security, and networked sensors.
6	BharatGen	India's multi-modal large language model initiative spearheaded by IIT Bombay, under National mission on inter-disciplinary cyber-physical systems
7	Skill India Digital Hub(SIDH)	https://swww.skillindiadigital.gov.in/pmkvy-landing
8	India AI mission	Govt. to provide 10K GPUs to provide compute-as-a-service at subsidized rates for startup, researchers
9	SAMARTH	Samarth scheme trained 3.2 lakh workers in skill development till March 2023
10	ATUFS	The Amended Technology Upgradation Fund Scheme (ATUFS) is a **Government of India scheme** that supports the textile industry by providing **financial assistance (capital subsidy)** for upgrading machinery and adopting modern technology.
11	Pradhan Mantri Kaushal Vikas Yojana (PMKVY 4.0)	Provides **free skill training + certification** Industry-aligned courses. Launched in 2022 – 23 website integrated into Skill India Digital Hub(7)
12	NAPS	Low risk for MSMEs National Apprenticeship Promotion Scheme (NAPS) o On-the-job training o Industry exposure https://fcbm.org/exciting-scheme-by-the-govt-of-india-to-boost-employment-and-skill-training-for-industrial-sector/
13	CSRD	EU's Corporate Sustainability Reporting Directive (CSRD).
14	Naan Mudhalvan [51]	This is a state-wide skill development initiative that bridges the gap between education and industry by providing training in emerging technologies, career guidance, and placement support to students.

15	MBSE	Model Based System Engineering
16	NVH	Noise Vibration and Harshness
17	Over-the-Air (OTA) update	**Software-Defined Personalization**: Tesla uses a centralized screen. "Personalized product" is delivered via **Over-the-Air (OTA) updates**—changing car's performance, or its entertainment features **long after it leaves the factory.**
18	Vertical integration	**Vertical Integration**: By making their own batteries and software in-house at Gigafactories, Tesla controls the entire "personalization" chain, allowing them to pivot production faster than traditional companies that rely on hundreds of outside suppliers.
19	Micro factories	Tesla uses a modular manufacturing process that can be reconfigured rapidly. If they want to change a specific part or process based on customer feedback, they can deploy new software modules to the factory robots almost instantly.
20	Car2X	Car2X is a cloud-based feature enabling real-time communication and interaction between the vehicle and the BMW production system during the production process. Car2X "transforms" every BMW on the production line into an active and connected participant in our industrial IoT (Internet of Things) ecosystem that self-analyses, interacts in real time with employees in the plant and automatically shares and documents relevant messages.
21	MSME	Micro, Small, Medium, Enterprise
22	Rejection rate	Rejection rate is the percentage of products that fail to meet quality standards and are rejected during or after production.
23	IPR	Intellectual Property Rights
24	Gigafactories	"Giga" refers to **gigawatt-hours (GWh)** These factories produce lithium-ion(Li-ion) **battery capacity in GWh scale**, which is extremely large.
25	**ESG**	Environmental, Social, and Governance
26	**Net Zero Adoption**	Cutting Carbon emissions to a small amount leaving zero in the atmosphere. https://www.un.org/en/climatechange/net-zero-coalition
27	**ZLD**	Zero Liquid Discharge (ZLD)
28	SIPCOT	State Industries Promotion Corporation of Tamil Nadu (SIPCOT) for large industries
29	SIDCO	For MSMEs
		SIPCOT → Land & Industrial Parks SIDCO → MSME Estates TIDCO → Mega Projects Guidance TN → Investment Attraction TIIC → Financing ELCOT(Electronics Corporation of Tamil Nadu) → IT/Electronics Parks

		TNIFMC → Infrastructure Funding TNSDC → Skilled Workforce TNPCB → Compliance TANGEDCO → Power Supply
30	NZIP	net-zero industrial park [40]
31	DISH	The Directorate of Industrial Safety and Health (DISH)
32	Net Zero Emissions (or "Net Zero")	Means balancing the amount of greenhouse gases emitted with the amount removed from the atmosphere

Table 3: Industry 5.0 and MSME Glossary

3 Who can benefit from this research report?

We strongly believe the following audience can benefit from the findings and recommendations captured in this research report.

- SMEs(Small Medium Enterprises), Tier 1 suppliers
- OEMs
- Central and State Govt. ministries and connected entities
    - MSME ministry
    - Skill development ministry
- IITM, NIT Trichy, and Engineering Institutes mentioned in section 10.5.
- Industry associations like ACMA, TEAMA, CODISSIA(see section 10.7 for more)

By absorbing and implementing the recommendations made in this report, MSME management can benefit from this report. Additionally, the Government administrators like secretaries or additional secretaries can draw data from this report for shaping Government policies.

4 Introduction

The main theme of this research work is Industry 5.0. Instead of analysing this theme in isolation, we want to analyse Industry 5.0 in the context of Tamil Nadu MSMEs. By contextualizing Industry 5.0 for MSMEs, we are able to bring out applications of Industry 5.0 for an important growth segment, namely, the MSME. According to Udyam dashboard[31], in India, there are 7.94 crore SMEs are there. Out of that 1.66 crores are in manufacturing. Importantly, MSME has generated 35 crore jobs.

Within T.N, though different MSME sectors are spread across different districts, Industry 5.0 should be viewed as a single integrating and all-embracing capability across different sectors.

It is a well-known statistic that Industries in TN have been growing continuously. The State consistently ranks first in exports in electronics, textiles, and leather products, and second in engineering exports[22]. Chennai as the Major hub for automobile in India, Coimbatore as Manchester of India, Tirupur as knitwear capital [21], and Sivakasi known as 'Mini-Japan' are proven manufacturing success stories. This was so even when MSME as a market didn't receive incentives and programmatic support.

Since the MSMEs contribute majorly to GDP growth (around **30.1%** in FY 2022–23) and employment generation, the topic of MSME (Micro Small & Medium Enterprise) has been receiving lots of attention and push from both Central and State Govts.

Govt. believes, MSME will be a sure-shot manufacturing growth opportunity for our country as witnessed by Taiwan and China. In addition, MSMEs are employment generators, they help in enhancing exports and contribute to country's GDP. The Government of India has set an ambitious vision of doubling the Indian economy to US$ 7 trillion by FY30. Achieving this goal will require strong support from MSMEs. Thus, the topic of MSME is extremely important and hence requires push from various dimensions. Industry 5.0 is one such dimension.

Though Industry 3.0/4.0 are all reasonably well understood, Industry 5.0 is a new and unfamiliar topic to many. But one aspect everyone understands is that the Industrial Revolutions are a result of transformative technology trends. Also, many are convinced about the digital transformation our country has witnessed and how many of the critical processes were carried out unhindered during Covid 19 pandemic.

By taking this one step ahead, Industry 5.0 architects have included sustainability and resilience as part of Industry 5.0 in addition to human-in-the-loop principle. As if the architects had premonition, we are already in the middle of another major geo-political tension leading to catastrophic energy crisis. Thanks to Industry 5.0, which has answers to this crisis in the form of sustainability. Industry 5.0 has been playing a critical role in the Electric Vehicle manufacturing(refer to the enclosed Tesla case study in Appendix). This is an answer to the fossil-fuel crisis, if not fully at least in part.

MSME and Industry 5.0 are vast topics. Hence, we have carved out the scope of our research. Instead of addressing the whole MSME domain, we have decided to focus only on those aspects of MSME which directly related to industry 5.0. Few such aspects are technology, sustainability, resilience, human resources, and skills.

5 Literature Survey

Globally driven Industry 5.0 or for that matter Industry 4.0 provides a foundational technology strategy for manufacturing organizations. Industries, only need to customize that strategy further to arrive at their own technology strategy. For the industries, I5.0 informs about the technology trends and which promising technology can address their challenges. Obviously, the technical teams need to invest time in POCs and pilots before actually adopting the technologies. Based on the results management can decide the investment decisions.

Mallick [4] of IDC have researched on Industry 4.0 adoption in startups. T.N Govt. formed committee delved deep into Industry 4.0 applicability to MSME [42]. Recently, in 2023, Ramachandran and others [7] published a report for T.N Govt explaining the industry 4.0 use cases in select T.N industries. The authors also explained the industry 4.0 maturity index. There are some in-depth analyses done by [6] on the competitiveness of MSMEs in India.

In 2024, IIT Madras organized a “Manufacturing & Industry 4.0” brainstorming workshop. Based on the workshop, a status report was submitted [Ramesh Babu, 18]. This report in general recommended strengthening the industry-Academia partnerships and expand reskilling initiatives. This workshop focussed mainly on Industry 4.0. “Surveyed the literature, we did not find any Indian MSMEs. So, we felt there is a need to study this in details”

In addition to the research papers and reports, we have also referred many publicly available data. We have kept them in reference.

6 Objective of this Research

- To suggest measures required for the adoption of Industry 5.0 as the growth strategy for SMEs.
- Articulate the benefits of positioning Industry 5.0 as an important strategic framework to enable SMEs to move up in the value chain
- To advise MSMEs to adopt Industry 5.0 within the manufacturing industry in India.

7 The Scope of the Research

We are conscious of the fact that the topic of Industry 5.0 applicable to MSMEs is the vast one. In order to bring out the insights in short period of time, it is essential to scope the work as part of wave 1.

- The viewpoints gathered in this research is drawn from thought leaders associated with Tamil Nadu SMEs.
- We have focused mainly on Industry 5.0. However, it should be noted that, in terms of technologies there is an overlap between Industry 4.0 and 5.0.
- The scope covers the following T.N districts for our research
    - Chennai, Kancheepuram (Total MSMEs in Kancheepuram (All Sectors) ~17,400+ manufacturing MSMEs Out of this, automobile + engineering MSMEs ≈ 1,800)
    - Tiruvallur, Chengalpattu, Virudhunagar, Krishnagiri, Trichy, Ranipet, Coimbatore, Tirupur (28,000+ MSME units across spinning, knitting, dyeing, printing, and garmenting each specialising in one link of the value chain.) and Trichy
- The scope covers the following focus industry sectors

Industry Sector	NIC Code	T.N clusters
Automotive	29	Chennai, Kancheepuram, Tiruvallur, Hosur
Textiles	13	Coimbatore
Garments/apparels	14	Tiruppur
Chemicals	20	Thoothukudi, Virudhunagar
Industrial Goods	25, 27, 28	Coimbatore, Trichy, Chennai
Precision Components	26, 28, 32	Coimbatore, Hosur, Sriperumbudur
Casting	24	Coimbatore

Table 4: Industry Sectors of interest

- In the wave 1 phase of research, we have only focused on Industry 5.0 technology and other related capabilities.
- In the Supplier-OEM relationship Table given below, our recommendations are aimed mainly at SME, Tier 1 and Tier 2 suppliers. Some of the recommendations hold-good for OEM as well.
- Though we may be using SME and MSME interchangeably, our work focuses only on SMEs/Tier 1/Tier 2 suppliers.

- Our work focusses primarily on skilled workforce

Level	Role	Example product
OEM	Final Product	Car
Tier 1	System supplier	EPS, brakes
Tier 2	Component supplier	gears, bearings
MSME	Small-scale supplier	raw parts, machining

Table 5 : Supplier-OEM relationship

8 Research Methodology

This research report on Industry 5.0 is only the first (wave I) of the many such research planned in the future on this topic. In Wave I, we have conducted this research based on interviewing thought-leaders drawn from leading OEMs, MSMEs, suppliers and industry organizations. These leaders are our personas representing different manufacturing industry domains such as textiles/garments, automobile, chemicals and industrial goods.

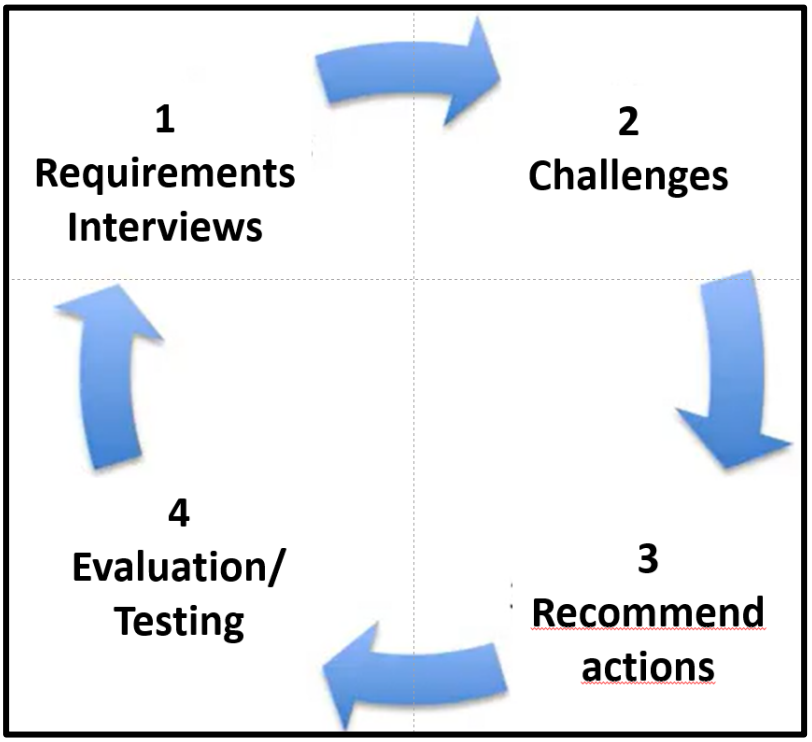


Figure 1: Research methodology

In this wave I, we have immensely learnt on the topic of Industry 5.0 and MSME ecosystem. After building our knowledge-base on the topic in this wave, in future we plan to delve deep into a particular cluster and do data driven study. Thus, our research methodology is based on

- Thought-leader interviews
- Literature survey
- MSME Field visits
- Interaction with Industry associations

9 Data Sources

1. Udayam - https://dashboard.msme.gov.in/
2. CMIE – Prowess DB
3. International Federation of Robotics
4. Enterprise Analysis Unit of the Development Economics Global Indicators Group of the World Bank
5. Open Data Government Portal (OSD), https://www.data.gov.in
6. World Robotics 2025
7. Polaris Market Research

10 Industry 5.0

Industry 5.0 is the latest edition of the Industrial evolution. It all started with Industry 1.0. Each evolution is characterized one or two disruptive technology transformations. Industry 1.0 was known for steam engines and railways. Industry 2.0 was well known for electrification, assembly line and mass production. Industry 3.0 had introduced automation, digital control using electronics and IT. Industry 4.0 brought in AI, Robotics and digitalization. In fact, many SMEs who had integrated Industry 4.0 were able to manage their operations during the Covid-19 lockdowns. Thanks to Industry 4.0.

We are currently in the midst of Industry 5.0 revolution which rightly introduced human-machine collaboration, sustainability and resilience. The word resilience has become extremely critical in the world where multiple wars are ongoing including the recent middle-east conflict. Indians can easily relate to Industry 5.0 culturally, as it blends tech-savvy innovation with a humanistic focus that resonates with our traditions.

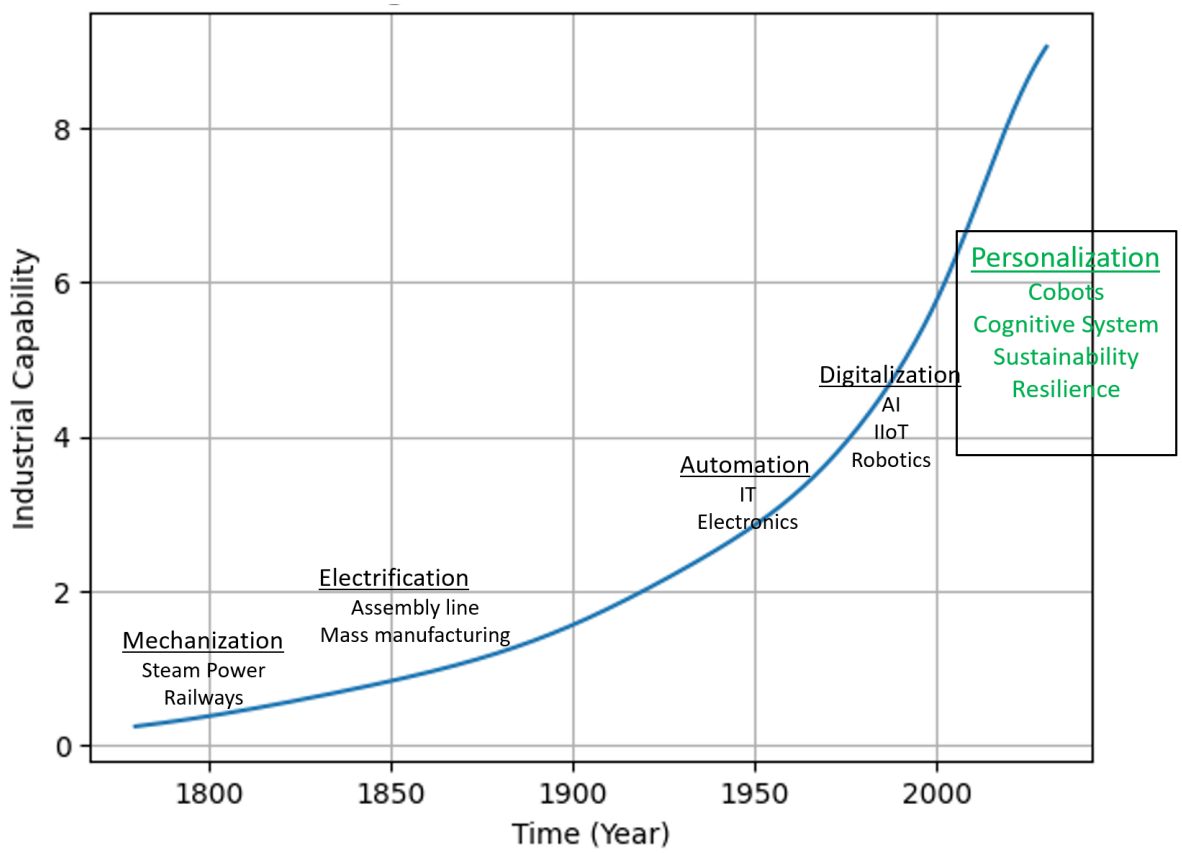


Figure 2 : Evolution of Industrial Revolutions

10.1 Comparison of Industry 4.0 and 5.0

Any discussion on Industry 5.0 is never complete without a discussion on comparison of Industry 4.0 and Industry 5.0. The enclosed table tries to further expand and refine the differences between the two already explained in Akundy et. al[17]. We have tagged Industry 5.0 capabilities as 5.x.x. This will be handy linking this capability with the solution we will discuss in the coming sections.

S.No	Characteristics	Industry 4.0	Industry 5.0 capability(5.x.x)
1	Focus	4.1.1 Smart manufacturing (smart mass production, smart products, smart working, smart supply-chain) 4.1.2 System(s) optimization.	5.1.1 Collaboration **5.1.2 Sustainability** 5.1.3 Resilience 5.1.4 Environmentally responsible 5.1.5 Humanization, empathy, **mass personalization** 5.1.6 Society conscious
2	Approach	4.2.1 Software defined 4.2.2 Real-time data monitoring, 4.2.3 Integrated chain that follows through end of life-cycle phases. 4.2.4 Replace humans	5.2.1 Software defined 5.2.2 Utilization of technology ethically to advance human values and needs, Socio-centric technological decisions, 5.2.3 7R methodology and logistics efficiency - Right {Product, Quantity, Condition, Place, Time, Cost, Customer} 5.2.4 Empower humans
3	Humanization	4.3.1 Human Reliability 4.3.2 Human-computer interaction 4.3.3 Repetitive movements	**5.3.1 Worker safety and management** 5.3.2 Learning/training for workforce 5.3.3 Empower humans
4	Technologies	4.4.1 Public Cloud 4.4.2 5G, Blockchain 4.4.3 Industrial Internet of Things(IIoT) 4.4.4 Big Data Analytics, 4.4.5 Digitalization (simulation, digital twins, AI, AR, VR),	5.4.1 Public Cloud 5.4.2 5G and beyond 5.4.3 Industrial Internet of Things (IIoT) 5.4.4 Big Data Analytics, 5.4.5 Digitalization (simulation, digital

		4.4.6 Automation (advanced robotics, remote monitoring, drones, autonomous robots, machine-to-machine communication), 4.4.7 Cyber-physical systems, 4.4.8 Horizontal and Vertical Integration (PLC, Supervisory Control and Data Acquisition(SCADA), Manufacturing Execution System (MES), Enterprise Resource Planning (ERP)), 4.4.9 Additive Manufacturing, 3D printing	twins, drones, **Physical AI**,AR/VR), **5.4.6 AI-Augmented Human Workforce[38],** Human-machine-interaction 5.4.7 Multi-lingual speech and gesture recognition, 5.4.8 Tracking technologies for physical occupational hazards, 5.4.9 **Collaborative Robots**, 5.4.10 Bio-Inspired safety and support Equipment, 5.4.11 Decision support systems, 5.4.12 Smart Grids, 5.4.13 Software defined 5.4.14 Predictive maintenance. **5.4.15 Additive manufacturing, 3D printing**
]5	Services	4.5.1 Traditional chat bots 4.5.2 Data centre hosting services	**5.5.1 AI Bots** 5.5.2 **AI factories**

Table 6 Comparison of Industry 4.0 and 5.0

adoption + use-cases give “instance counts”, based on the use cases in various auto industries like BMW, Hyundai, Tesla. Based on multiple industry S&P, Statista, IoT/IIoT reports

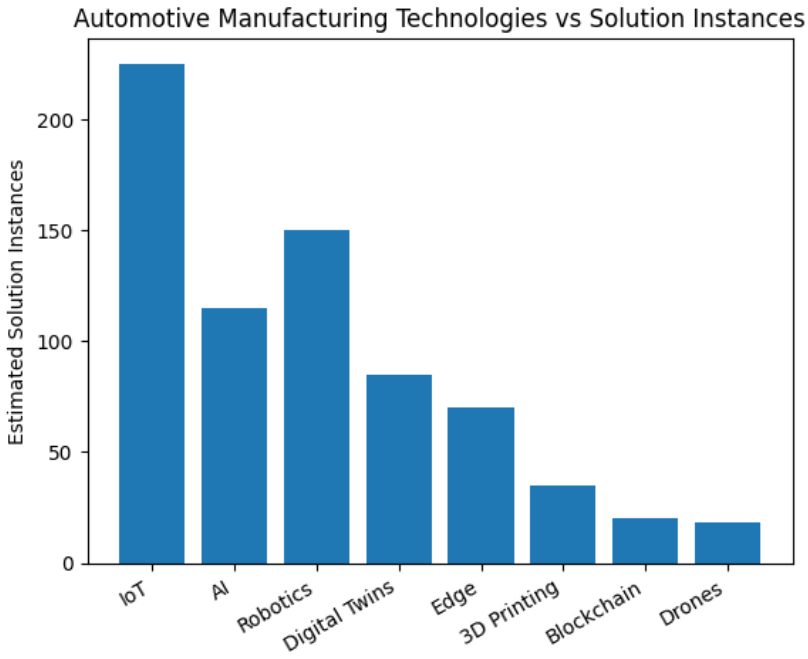


Figure 3: Automotive Technologies and solution instances

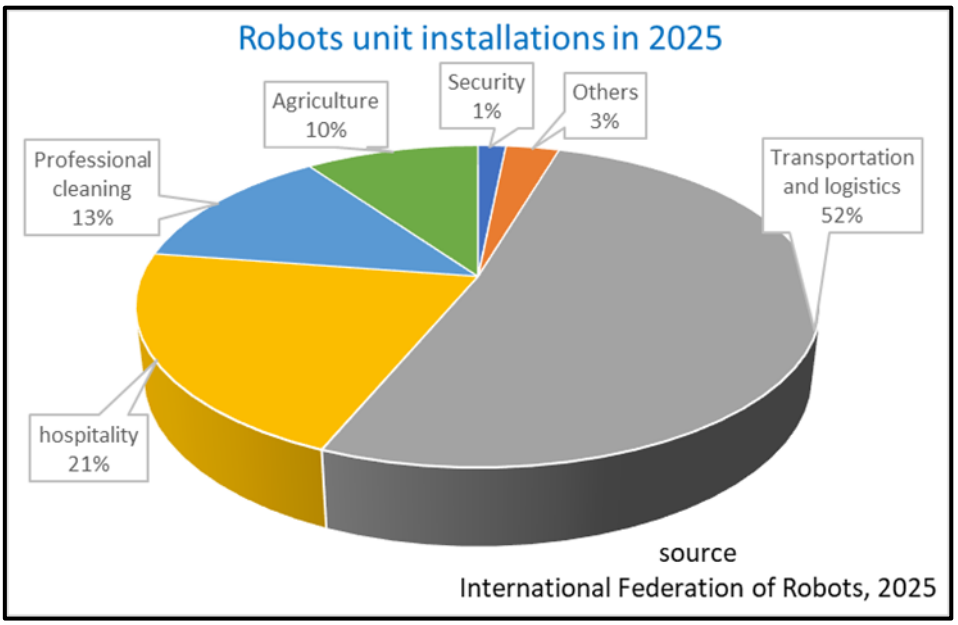


Figure 4 : Robots installation, Figure 6 and 7 Li-ion battery capacity by state

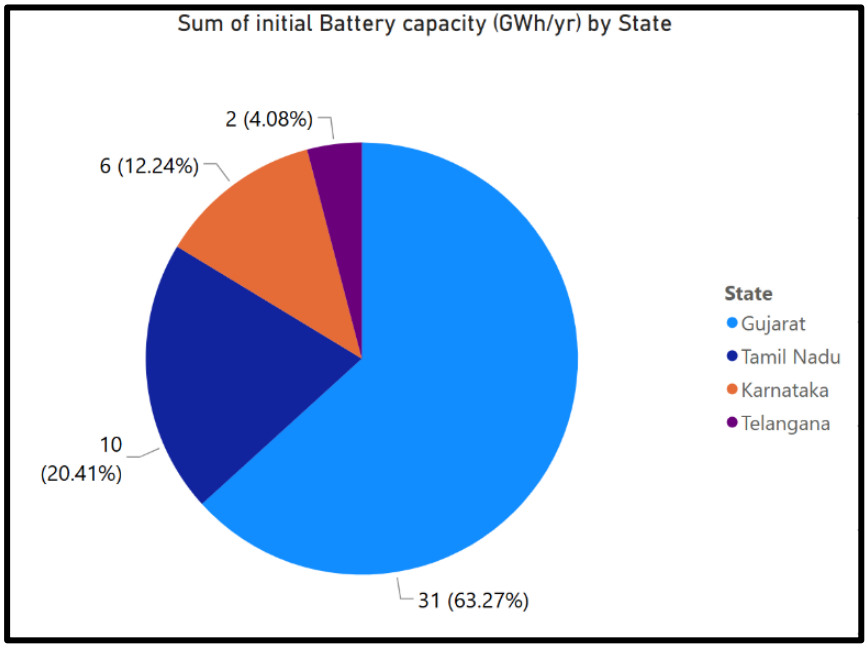


Figure 6: Sum of initial Li-ion Battery capacity by State

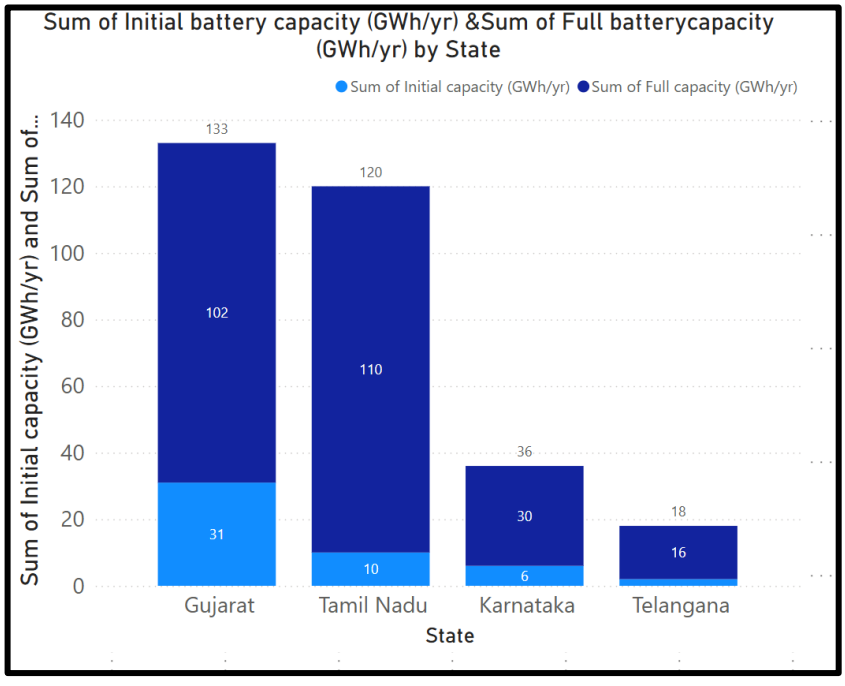


Figure 7: Sum of initial Li-ion battery capacity & Sum of full battery capacity by State

10.2 Industry 5.0 Reference architecture- RAMI 5.0

Reference architecture is very helpful in building a common language for discussions amongst stakeholders [29]

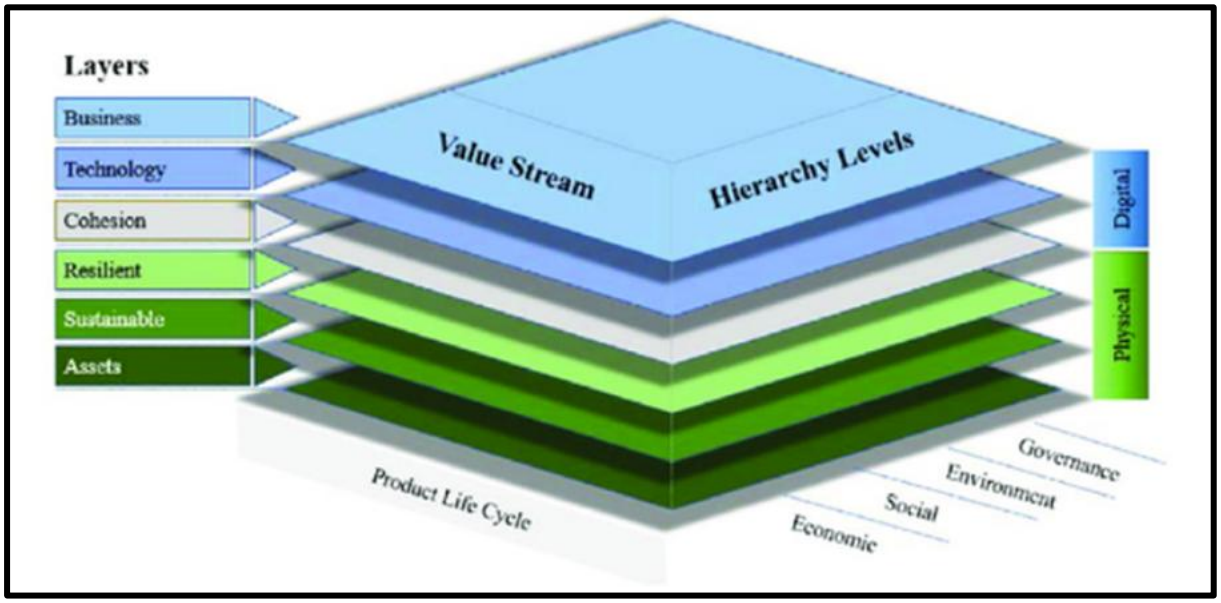


Figure 5: Industry 5.0 Reference architecture

10.3 Industry 5.0 Benefits to MSMEs

> " Disruptive technologies typically enable new markets to emerge"
> *-Clayton M Christensen*

- Industry 5.0 provides a globally aligned, technology strategy for Indian MSMEs and particularly Tamil Nadu SMEs
- The backbone of Industry 5.0 is Technology. Even if MSME workforce may or may not possess Tech skills today, Tamil Nadu as a state is well known for technical skills. T.N SMEs need to effectively and systematically utilize this advantage to their benefits.
- The main motto of this research is to elevate MSMEs up in the value-chain. Strategically speaking, getting the designs from OEMS and manufacturing exactly as per the supplied blue-print alone might not benefit MSMEs in the long run. MSMEs are not part of conceptualization, innovation, R&D, and design.
- As lucidly explained in the research by Stan Shih, the founder of Acer Inc., in 1992., by doing the manufacturing alone, the MSMEs will continue to remain at the bottom of the 'Smile-curve-of- sterilization', lowest value in the product development life cycle. The curve as shown below graphically illustrates how the value addition varies across the stages of a product's development and distribution.

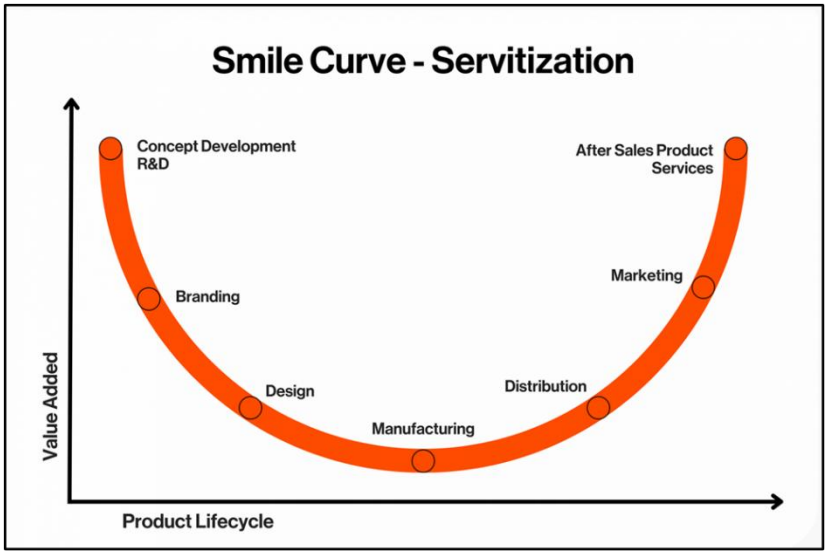


Figure 8 : Stan Shih's Smile-curve-of-servitization

Courtesy:https://www.ureason.com/resources/the-smiling-curve-of-servitization/

- The Acer company adopted a business strategy to reorient itself from manufacturing into global marketing of brand-name in PC-related products[30].

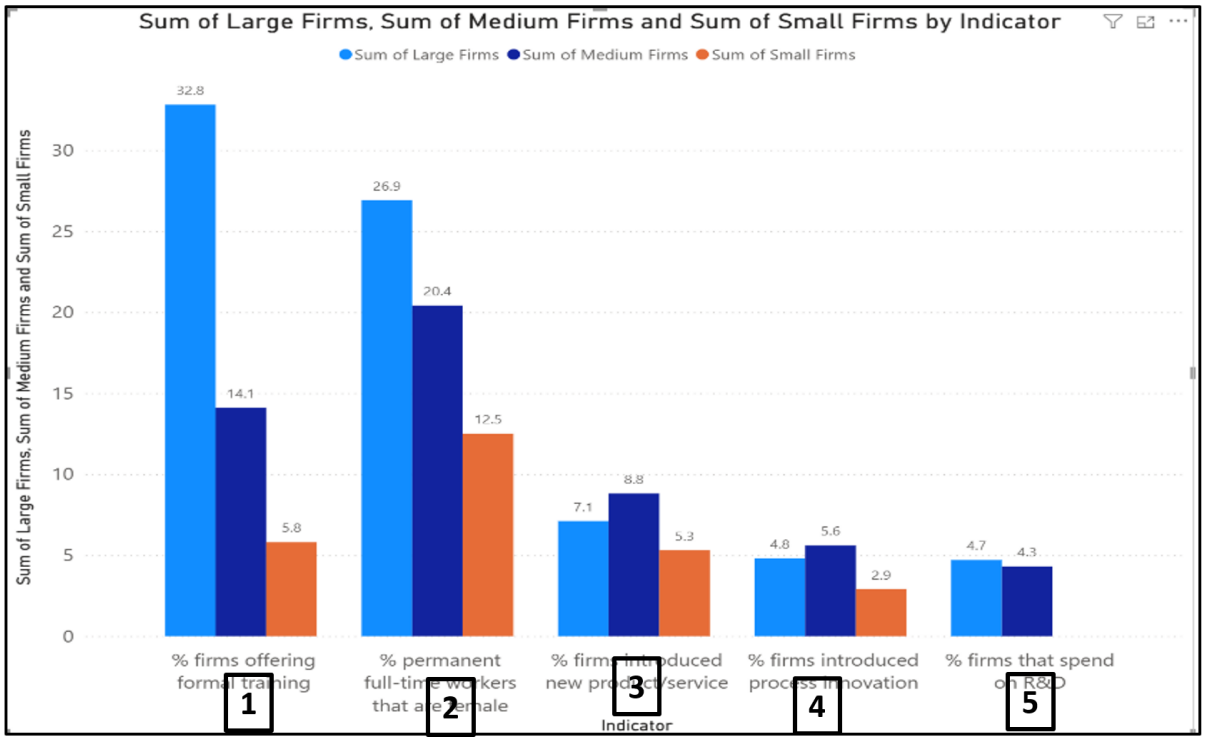


Figure 9: 1. % firms offering formal training, 4. %firms introduced process innovation 5. % firms that spend on R&D

Source: World Bank Enterprise Surveys 2022, www.enterprisesurveys.org

- Thus, the Industry 5.0 is very relevant to MSME. This if seriously adopted would elevate the T.N MSMEs up in the value chain.
- In addition, Industry 5.0, R&D and innovation are also critical for adding more value to the product Life cycle. That is why, this research recommends, setting up of community R&D and innovation hubs(section 8.9) in MSME clusters.

10.4 Industry 5.0 Solutions

10.4.1 Industry 5.0 Solution descriptions

Though there are more Industry 5.0 solutions, we have highlighted only the four popular ones.

10.4.1.1 Cobots

A robot designed to work physically alongside human workers in a shared workspace, prioritizing safety through sensors, force limitation, and rounded, lightweight design.

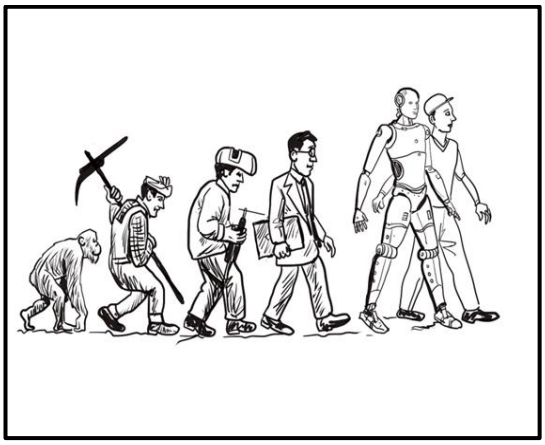


Figure 10**a**: Evolution leading to cobots

Unlike traditional robots that require safety cages, cobots are designed to stop automatically upon contact with a person. In Figure 10, a human is working with a Cobot.

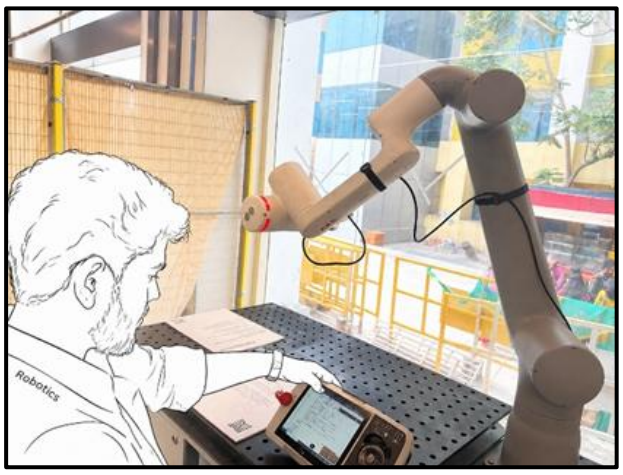


Figure 10b: ABB Cobot Model – Collaborative Robot – GOFA – 15000

10.4.1.2 Predictive Maintenance

Predictive maintenance is a condition-based maintenance approach that utilizes real-time monitoring and data analytics to anticipate equipment failures in industry and perform maintenance only when required. Unlike traditional preventive maintenance methods that rely on fixed maintenance schedules, predictive maintenance continuously evaluates machine health using sensor-generated machinery-data. This reduces unnecessary

maintenance activities, minimizing downtime, and improving asset reliability. According to the NASA Lessons Learned Information System (LLIS)[43], predictive maintenance enables timely intervention before catastrophic failures occur and supports efficient maintenance planning. Predictive maintenance could be used to prevent human causalities from industrial blasts due to high temperature in furnaces , high pressure is boilers

Modern predictive maintenance systems extensively utilize predictive analytics part of AI/ML and anomaly detection algorithms to identify early signs of equipment degradation and failure. These algorithms analyse real-time sensor and vibration data to detect hidden patterns, predict faults, and optimize maintenance schedules. In Industry 4.0/5.0 environments, predictive maintenance systems are further enhanced through the integration of IIoT-enabled sensors, and digital twins.

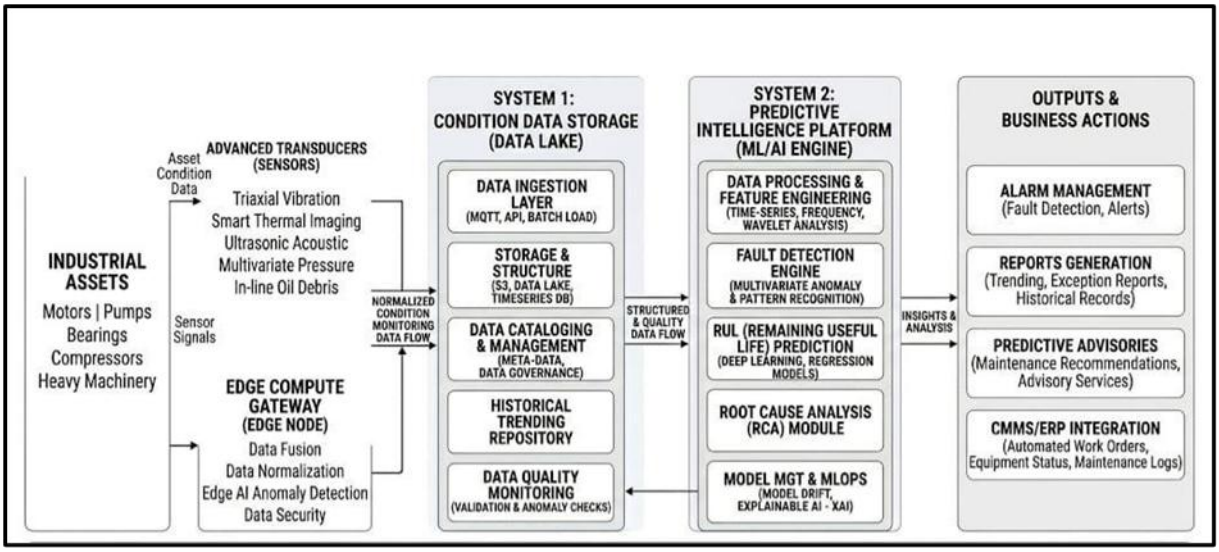


Figure 11a: Predictive maintenance solution

A critical capability within predictive maintenance is Remaining Useful Life (RUL) prediction, which estimates the remaining operational lifespan of machinery or components before failure occurs. RUL prediction uses historical and real-time sensor data together with machine learning and deep learning algorithms to assess equipment degradation patterns and overall machine condition. Accurate RUL prediction supports condition-based maintenance strategies, improves operational reliability, enhances equipment utilization, reduces unplanned downtime, and extends asset life.

Data quality and availability play a vital role in the development of reliable AI-based predictive maintenance models. Consequently, authentic industrial datasets are essential for research, learning, validation, and implementation of predictive maintenance solutions. One widely used benchmark dataset is the NASA Bearing Dataset[44], a prognostic dataset developed for predictive and preventive maintenance applications.

The NASA Bearing Dataset consists of four Rexnord ZA-2115 double-row bearings mounted on a shaft rotating at a constant speed of 2000 RPM with a radial load of 6000 lbs. Vibration

signals were captured using PCB 353B33 High Sensitivity Quartz ICP accelerometers installed on the bearing housings. Data was collected from three run-to-failure experiments, where each file contains a one-second vibration signal snapshot comprising 20,480 data points sampled at 20 kHz. The dataset was provided by the Center for Intelligent Maintenance Systems (IMS), University of Cincinnati, and originally collected by NASA Ames Research Center.

Another valuable resource for implementing predictive maintenance solutions in industrial environments is the MATLAB-based predictive maintenance framework provided by MathWorks Predictive Maintenance Resources, which offers practical workflows for machine condition monitoring, fault diagnostics, and RUL estimation using AI and data analytics techniques.

10.4.1.3 Manufacturing Digital Twins

A Manufacturing Digital Twins is a dynamic, virtual representation of a physical manufacturing system that continuously integrates real-time data from shop-floor assets, processes, and utilities to simulate, monitor, predict, and optimize operations across the lifecycle.

It is a five-layer architecture solution.

L1: Physical Layer (Sensors & IoT Layer) responsible for Capturing real-world data from machines, compressors, furnaces, engines and turbines. This outputs High-frequency raw data

L2: Data Integration Layer responsible for Transforming fragmented data into structured data. This outputs contextualized dataset.

L3: Creates the virtual replica (the Twin). Uses Physics-based models (process simulation) and AI/ML models (prediction & optimization. Outputs Predictions like failures or anomalies, high temperature, high pressure, etc. Tasks like visualization or monitoring and actions to be taken can be part of this layer

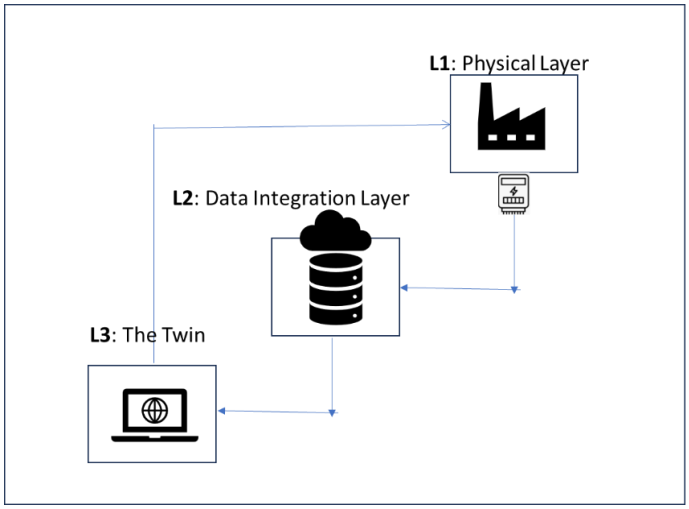


Figure 11b: Manufacturing digital twin's flow

10.4.1.4 Additive Manufacturing

Unlike subtractive manufacturing, which carves parts out of a solid block, AM uses only the material required for the part, drastically reducing raw material waste. Clearly, AM thus aligns with the sustainability principle of Industry 5.0.

From the solid block, the subtractive manufacturing removes parts of unwanted portion. Whereas AM uses only the metal or polymer required for that part. This is a huge reduction in wastage.

Additive manufacturing is the broad industrial process of creating objects layer by layer, while 3D printing is the most common and widely known method used to implement this process.

Popular 3D printers are :

Feature	EOS M 290	EOS P 396
Material	Metal	Polymer
Use	High-strength industrial parts	Prototypes & lightweight parts
Industry	Aerospace, automotive	Automotive, consumer goods

Table 7: Sample 3D printers

Automotive sector = biggest driver

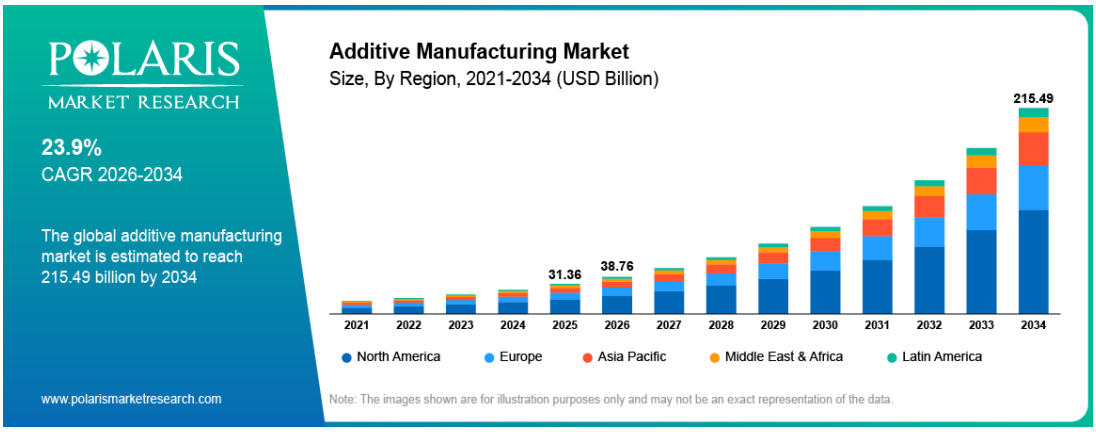


Figure 12a: Industry 5.0 growth indicators – Additive Manufacturing Market growth

10.4.2 Industry 5.0 Solution Roadmap

MSMEs, Tier 1, Tier 2 manufacturers if they are new to Industry 5.0, would be wondering where to start. This Roadmap can be a good starting point. However, based on the industry, size and their current maturity level, this road map might require changes.

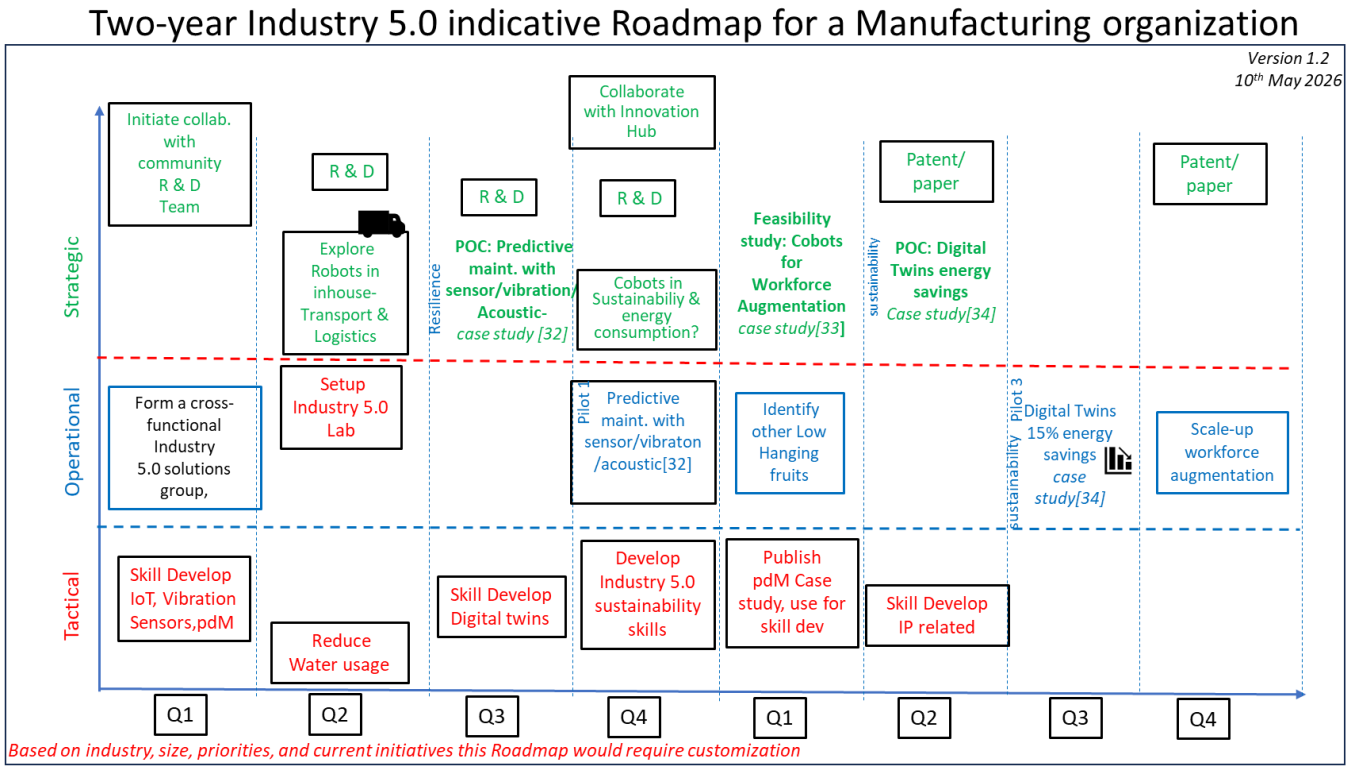


Figure 12b: Sample Industry 5.0 Roadmap

*MSMEs can explore using pay per use Robots offered by Metalman Automation(https://www.industrialautomationindia.in/directory/metalman-automation-pvt-ltd) or other companies.

10.4.3 Funding access for MSMEs

Here are key recommendations to enhance cash flow and funding access for MSMEs, addressing structural barriers in technology adoption, finance, and policy support.

Hire Robotics Expertise

MSMEs often lack capital for in-house robotics investments. Recommend enabling on-demand hiring models through platforms or partnerships, allowing firms to access specialized expertise without long-term commitments, thereby preserving cash flow.

Corporate-MSME Partnerships

Major corporates should lead Industry 4.0/5.0 adoption by offering R&D support and pilot programs to MSMEs. This builds confidence on ROI through shared demonstrations, fostering collaborative ecosystems that reduce upfront costs and unlock productivity gains.

Reduce Interest Rate Disparities

Despite supportive policies, mid-sized MSMEs face high interest rates compared to large corporates. Propose tiered lending frameworks or government-backed guarantees to lower borrowing costs, improving cash flow parity and enabling competitive scaling.

Boost Scheme Awareness

Low awareness of funding schemes hampers uptake. Advocate for centralized, user-friendly portals with clear eligibility guidelines, multilingual guides, and regional workshops to simplify access and accelerate disbursal.

Segment Industries at Registration

Provide targeted manufacturing thrust by mandating segment classification (trading, services, manufacturing) during business registration. This enables precise policy incentives, priority funding, and tailored cash flow support for manufacturing MSMEs.

Enhance Portal Interoperability

Study and implement interoperability across TReDS portals to create a unified invoice discounting ecosystem. Seamless integration would minimize fragmentation, lower transaction costs, and improve liquidity options for MSMEs.

Prioritize NGO Support

NGOs aiding MSMEs should receive preferential listing on social stock exchanges. This channels impact investing into grassroots funding, diversifying cash flow sources and amplifying sustainable growth for underserved enterprises.

10.5 Engineering Institutes in Tamil Nadu working in related area

Engineering institutes related to Industry 5.0

1. IIT Madras
2. Anna University
3. NIT Trichy
4. IIM Trichy
5. VIT, Vellore
6. TCE Madurai
7. IIIT Kanchipuram
8. SRM Easwari Engineering
9. RIT
10. MEPCO, Sivakasi
11. SSN Chennai
12. PSG Institute of Technology, Coimbatore
13. Coimbatore Institute of Technology

10.6 Centre of Excellence(Coe), and Research Centres in TN

Engineering institutes doing research and consultancy projects related to Industry 5.0

1. Smart Manufacturing & Digital Transformation Centre (SMDTC) , IIT M
2. Engineering asset management (EAM) group, department of mechanical engineering, IIT-M.
3. Centre for Internet of Things (IoT), Centre for Robotics and Automation, Centre for Artificial Intelligence, Data Science Research and Applications, Anna University main campus
4. Centre for Innovative Manufacturing Research (CIMR), VIT Vellore
5. Siemens CoE – Manufacturing, Industrial Automation Research Lab (EEE), CoE in Automation, NIT Trichy
6. Centre of Excellence – in collaboration with Nokia Solutions and Networks India Pvt Ltd, SRM Easwari Engineering College
7. Centre for Wireless Communication / Embedded Systems, TCE Madurai
8. Centre for Advanced CNC and Robotics, certified Fanuc-based training, Centre for Industrial Automation (CIA), PSG College Coimbatore
9. Smart Manufacturing Lab, IIITDM, Kanchipuram
10. School of Advanced Computing and Engineering – SACE, SSN College of Engineering, Kalavakkam, Chennai
11. Sardar Vallabhbhai Patel International School of Textiles & Management, Coimbatore
12. The South India Textile Research Association, SITRA, is a textile research association established in 1956 at Coimbatore,

10.7 Other Key Industry 5.0 stakeholders

Among the many stakeholders, few key stakeholders are given below:

- Engineering Institutes mentioned in section 10.5
- CoE and Research Labs mentioned in section 10.6
- Various Industry associations in MSME clusters in T.N
- "Laghu Udyog Bharati" (LUB)
- Nettur Technical training Foundation
- State Industry Secretary, Tamil Nadu
- SIPCOT - State Industries Promotion Corporation of Tamil Nadu Limited
- TANSIDCO (Tamil Nadu Small Industries Development Corporation)
- TIDCO
- MCCI (Madras Chamber of Commerce)
- TANSTIA -Tamil Nadu Small and Tiny Industries Association
- UNIDO, United Nations Industrial Development Organizations
- Tamil Nadu Skill Development Corporation (TNSDC)
- TIIC – T.N Industrial Investment Corporation, NBFC
- ATAL Tinkering Lab – in colleges- for infra dev – new Startup - DPIT
- PM Kaushal Vikas Yojana
- PM Employment Generation Program
- Z program – Bronze, Silver, Gold(Govt itself is running, only Bronze is
- MSME SAMADHAAN
- SAMARTH Udyog Bharat 4.0
- AICTE, New Delhi
- Institutes listed under section 10.5
- TEAMA – Tirupur Exporters and Manufacturers Association

10.8 Compliance and Industry 5.0

Most of the standards enforce sustainability, which is also one of the key principles of Industry 5.0.



Figure 13: Compliance is critical for exports

Thus, compliance to standards ensure manufactured products fulfil the sustainability criteria. Most importantly, such products are permitted to export to other countries and hence can access global markets. This expands the addressable market space for the manufactured goods. The downside is there is a cost to compliance.

1. **CBAM** (Carbon Border Adjustment Mechanism) is mandatory for EU/US supply chain
2. The Global Organic Textile Standard (**GOTS**) is a globally recognized certification system for organic textiles, ensuring that products are made from certified organic fibres and processed under environmentally and socially responsible conditions across the entire supply chain.
3. **OEKO-TEX** certifies textiles and leather products by testing for toxic chemicals and harmful substances, ensuring consumer safety and compliance with international health standards.
4. **REACH** (EU Regulation)
5. **RoHS** (Restriction of Hazardous Substances)
6. ISO 9001 – Quality management
7. ISO 14001 (Environmental Management)
8. GDPR – Global Data Protection Regulation

10.9 Industry 5.0 Core themes and Best Practices

Mass personalization :

More than 50% of consumers say they’re interested in personalized products and they're willing to pay a premium for them (courtesy Deloitte study)

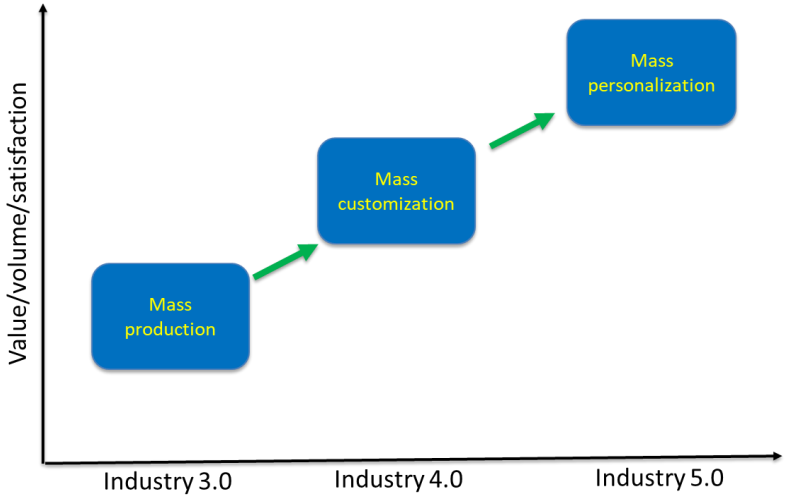


Figure 14: Difference in thematic goals between last three Industrial revolutions

Companies embracing advanced customization tech have improved lead times by 10–20% and customer satisfaction by up to 30% (courtesy McKinsey study)

Vertical Integration

By making their own batteries and software in-house at Gigafactories, Tesla controls the entire "personalization" chain, allowing them to pivot production faster than traditional companies that rely on hundreds of outside suppliers.

Sustainability

Water reuse and energy efficiency, achieving carbon neutrality in its operations, low-carbon products, renewable energy storage, reduced CO2 emissions with EV, lithium-ion(Li-ion) battery technology, and non-conventional energy sources.

Net-zero emissions manufacturing

Net-zero emissions in manufacturing involves balancing greenhouse gases produced by industry with an equivalent amount removed from the atmosphere, crucial for limiting global warming. Achieving this requires aggressive emission reductions—using renewable energy and efficiency—alongside carbon capture and removal technologies, aiming to eliminate or offset all industrial carbon footprints.

Physical AI

Physical AI lets autonomous systems like cameras, robots, drones and self-driving cars perceive, understand, reason, and perform or orchestrate complex actions in the physical world.

Human in the loop

AI model that incorporates human interaction to improve accuracy, safety, and decision-making by combining machine speed with human judgment. It acts as a critical feedback mechanism where AI flags uncertain data for human review, refining its learning and reducing bias.

Collaborative Robots(Cobots)

If we consider the growth of Industrial robots' deployments as an indicator for Industry 4.0/5.0 adoption, then as shown in the below graph, as the 6th largest user of robots, India is doing well with Industry 4.0/5.0 adoption. Keep in mind that there are other parameters as well.

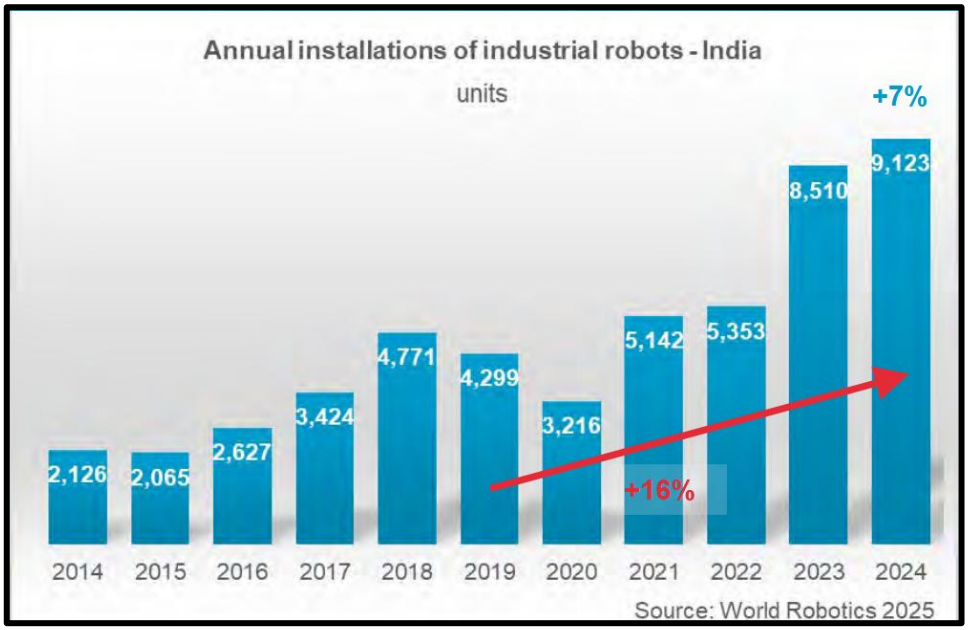


Figure 15: Industry 5.0 growth indicators – Annual Robots installation

AI factories

AI factories are specialized, high-performance computing data centres designed to continuously generate intelligence by processing massive datasets, acting as modern, industrial-scale producers of AI models and tokens. Unlike traditional data centres for IT applications, AI factories integrate GPU-centric hardware with software for end-to-end AI lifecycles, including training and inference.

Zero Defect Manufacturing(ZDM)

Treats quality as an investment rather than a cost

Preventative Focus: Unlike traditional quality control, which detects defects after they occur, ZDM uses data-driven technologies to prevent defects from happening.

Industry 5.0 Technologies: Implementation relies on advanced tools such as:

- **Sensors:** To monitor machine data in real-time.
- **Computer Vision/AI:** For automatic, real-time inspection.

- **Data Analytics:** To understand defect causes and propagation.

Seven pillars of India AI mission:

For Industry 5.0 AI workloads, Compute-as-a-service can be used. For skills, AI future skills pillar can be leveraged.

Industry Best Practices

1. All major OEMs are converging towards a **common model**: **AI + Digital Twin + Real-time Data = Smart Manufacturing + NVH** (Noise, Vibration, and Harshness)**Optimization**
2. While trying to get a management buy-in for Industry 5.0 initiatives, pitch Industry 5.0 problem-solving capabilities than with Industry 5.0 lingo
3. First Identify your manufacturing industry problem that a specific Industry 5.0 technology can address. Then leverage that particular I5.0 technology. Take solution-first approach than getting into the details of I5.0.
4. Then evaluate and adopt sustainability and resilience aspects of Industry 5.0, if not already implemented.
5. Any new project pilots should be substantiated with financial Business case
6. Refer to the roadmap (Figure 12b) and align with reference architect (Figure 5)

11 Mapping industry specific processes to Industry 5.0 Technology solution component

NIC	Sub-Sector Category	Specific Component/Service	Key OEM Demand Drivers	Industry 4.0/Industry 5.0 Solution/capability Mapping
29.1	Engine & Powertrain 29	Pistons, rings, cylinder liners	ICE and hybrid Engines	29.1 Smart machining with CNC/IIoT process monitoring
29.2		Crankshafts & camshafts	Precision machining requirements29301	29.2 CNC automation and in-line metrology
29.3		Connecting rods	Lightweight materials adoption29301	29.3 Digital twin for material-performance optimization
29.4		Engine valves & tappets	High-temperature durability29301	29.4 AI-based predictive quality for heat treatment
29.5		Gaskets & seals	Electric motor sealing needs29301	29.5 Machine vision inspection and traceability
29.6		Turbocharger components	Efficiency improvement29301	29.6 Simulation-driven design and digital twin validation
29.7		Fuel injection systems	Hybrid and flex-fuel applications	29.7 High-precision robotics and smart test benches
27.8	EV & Battery Systems 27	Battery pack enclosures	Thermal management, safety	27.8 Digital twin and thermal simulation
27.9		Busbars & connectors	High-voltage applications	27.9 Vision-guided robotic assembly
27.10		Battery management system (BMS) PCBs	Electronics integration	27.10 SMT automation with AI-based optical inspection (27.10)
27.11		Cooling plates & thermal interface materials	Battery temperature control	Process analytics for thermal dispensing and leak testing(27.11)
27.12		High-voltage wiring harnesses	EV-specific certification	Digital work instructions and end-to-end traceability(27.12)
27.13		Charging inlet assemblies	AC/DC fast charging standards	Automated electrical end-of-line testing(27.13)
27.14	Electronics 26 & Electrical 27	PCB assemblies (PCBA)	ADAS, infotainment, controls	Smart factory SMT line with AOI and MES integration(27.14)

NIC	Sub-Sector Category	Specific Component/Service	Key OEM Demand Drivers	Industry 4.0/Industry 5.0 Solution/capability Mapping
27.15		Sensors (pressure, temperature, position)	SDV and automation needs	MEMS/sensor calibration automation with analytics(27.15)
27.16		Electric motors (BLDC, stepper)	HVAC, actuators, pumps	Cobots for winding/assembly and predictive maintenance(27.16)
27.17		Switches & control modules	Interior electronics	Flexible automation with poka-yoke and traceability(27.17)
27.18		LED lighting assemblies	Exterior and interior lighting	Machine vision alignment and automated photometric testing(27.18)
29.19	Transmission & Driveline 29	Gears & gearboxes	EV reduction gears, DCT	Smart gear machining with condition monitoring
29.20		Differential cases	Precision casting	Connected foundry and casting simulation(29.20)
29.21		Drive shafts & CV joints	AWD and EV applications	Robotic balancing and torque traceability(29.21)
29.22	Suspension & Steering 29	Control arms & linkages	Lightweight forged components	Forging analytics and digital process control (29.22)
29.23		Shock absorber components	Ride comfort requirements	Automated test rigs with real-time data capture(29.23)
29.24		Steering columns & linkages	Electric power steering	Cobot-assisted(I5.4.9) assembly with torque monitoring(29.24)
29.25		Ball joints & tie rods	Durability standards	Predictive quality and life-cycle fatigue analytics
29.26	Braking Systems 29	Brake callipers	Regenerative braking integration	CNC machining cells with smart quality control
29.27		Brake pads & friction materials	Low-dust formulations	Material informatics and automated mixing control
29.28		Brake lines & hoses	High-pressure capability	Leak testing automation and SPC dashboards

NIC	Sub-Sector Category	Specific Component/Service	Key OEM Demand Drivers	Industry 4.0/Industry 5.0 Solution/capability Mapping
29.29	Body & Structure25	Sheet metal stampings	Structural components	Smart stamping press monitoring and die analytics
29.30	29	Welded assemblies	Chassis frames, subframes	Robotic welding with machine vision
29.31	25	Forged components	Steering knuckles, hubs	Connected forging lines with energy monitoring
29.32	25	Aluminium castings	Lightweighting initiatives	Casting simulation and digital twin process optimization
29.33	Interior & Trim 29	Injection moulded plastics	Dashboard, door panels	Injection moulding process monitoring and MES
29.34		Seat structures & mechanisms	Ergonomic and safety standards	Collaborative robotics for assembly and testing
29.35		Interior textiles & upholstery	Sustainability requirements	Sustainable manufacturing analytics and digital traceability
29.36		Soft trim & headliners	NVH reduction	AI-driven defect detection for trim quality(29.36)
29.37	HVAC & Thermal 29	HVAC modules	Cabin comfort, battery cooling	Smart assembly lines and thermal performance analytics(29.37)
29.38	29	Radiators & heat exchangers	EV thermal management	Digital twin for thermal-flow optimization(29.38)
28.39	28	Cooling fans & blowers	Energy efficiency	IoT-enabled motor testing and efficiency analytics(28.39)
28.40	Fasteners & Hardware 25	High-strength fasteners	Critical assemblies	Automated fastening systems with torque data capture(28.40)
28.41		Clips & retainers	Assembly efficiency	Flexible automation and vision inspection(28.41)
42	Rubber & Sealing 22	Weather seals & door seals	NVH, water ingress prevention	Extrusion process monitoring and quality analytics
43		Vibration dampers	Electric motor NVH challenges	Simulation-led NVH engineering and smart validation

NIC	Sub-Sector Category	Specific Component/Service	Key OEM Demand Drivers	Industry 4.0/Industry 5.0 Solution/capability Mapping
44		Hoses & tubing	Fluid and coolant transfer	Connected extrusion lines and leak-test automation
45	Surface Finishing 25	Electroplating & coating	Corrosion protection	Smart bath chemistry monitoring and SPC
46		Painting services	Aesthetic and protective	Robotic paint shops with AI defect inspection
47	Forging & Casting 24	Investment castings	Complex geometries	Digital casting simulation and additive tooling support
48	24	Die castings (Al, Zn, Mg)	Lightweight structural parts	High-pressure die-casting monitoring with digital twin
49	Machining Services 25	CNC precision machining	Critical tolerance components	IIoT-enabled CNC cells with predictive maintenance
50	Tooling & Molds 28	Injection Molds, dies	Production tooling	CAD/CAM integration and digital tool-life management
14.1	Garment Manufacturing	Cut & Sew Apparel	Mass production, export demand, fast fashion cycles	Automated cutting (CNC), sewing automation, MES systems (14.1)
14.2	Knitted Apparel	T-shirts, Hosiery	High-volume export demand, comfort wear trends	IoT-based production monitoring, AI demand forecasting
14.3	Technical Apparel	Protective/functional clothing	Defence, healthcare, industrial safety demand	Smart textiles, embedded sensors, digital twin testing
14.4	Fashion & Design	Custom garments, designer wear	Customization, rapid design changes	CAD/CAM, virtual prototyping, 3D garment simulation
14.5	Embroidery & Value Addition	Embroidery, printing	Brand differentiation, aesthetics	Computerized embroidery, digital printing, AI-based design tools
14.6	Processing & Finishing	Dyeing, washing, finishing	Quality consistency, sustainability norms	IoT sensors, water/energy monitoring, predictive analytics
14.7	Quality Control	Inspection & compliance	Export standards, zero-defect demand	Vision-based inspection, AI defect detection
14.8	Packaging & Logistics	Packing, labeling, export logistics	Global supply chain efficiency	RFID tracking, warehouse automation

NIC	Sub-Sector Category	Specific Component/Service	Key OEM Demand Drivers	Industry 4.0/Industry 5.0 Solution/capability Mapping
14.9	Leather Apparel	Jackets, leather garments	Premium fashion demand	Laser cutting, material optimization software
14.10	Custom Tailoring	Made-to-measure clothing	Personalization trend	3D body scanning, mass customization platforms
14.11	ZLD	Zero Net Emission		Zero Liquid Discharge (ZLD)

Table 8: Mapping Industry processes to Industry 5.0 solutions

The Table 8 is organized based on National Industry Code (29, 27, 14)covers only the mapping of automotive and precision engineering, textiles sectors. It will be useful to MSMEs if such mapping could be extended to other industries like Food Processing, chemical/matches/Fireworks, leather, space technology, and Defence manufacturing.

Thanks to TANSTIA [section 10.7] for sharing automobile industry specific processes.

12 Industry 5.0 Adoption Challenges faced by MSME

Based on our extensive research of past reports on this topic[5,7,17,18] and also based on the interviews with industry thought-leaders, we have captured the challenges faced by SMEs in adopting Industry 5.0

S. No	Challenges	Criticality(High /medium/low)
C1	A large portion of the workforce lacks formal vocational or technical training, which hampers productivity and limits the ability of MSMEs to scale effectively.	High
C2	Many MSMEs also fail to invest sufficiently in research and development (R&D), quality improvement, or innovation, making it difficult to stay competitive in national and global markets.	Medium
C3	MSMEs face barriers in adopting modern technologies due to unreliable electricity supply, weak internet connectivity and high capital investment	High
C4	Many MSMEs are either unaware or unable to access central/state government schemes designed to support MSMEs.	High
C5	The latest accurate data of MSMEs in India and in T.N are not available. The data available in published reports are old. The data available in Udyam portal is not reflecting the real data.	High
C6	Overall High-level gaps in MSMEs identified by the Central Govt: 1. Low participation of women. 2. Limited industry alignment. 3. Weak integration with formal education. 4. Insufficient focus on emerging technologies (AI, robotics, renewable energy). 5. Lack of standardization. 6. Limited apprenticeships and on-the-job training. 7. Regional/rural imbalance. 8. Informal sector neglect. 9. Weak industry participation. 10. Digital divide.	Critical

S. No	Challenges	Criticality(High /medium/low)
	11. Limited data and tracking systems.	
C7	AI is an integral part of Industry 5.0. As part of the AI India mission, the Central Govt. has rolled out programs for providing the GPU based AI infrastructure on the cloud. Further Govt. has also launched AI future-ready skills program for providing AI training for the workforce [25],India AI compute and India AI future skills. Appendix A10: India AI Mission. But MSME workforce hasn't fully exploited these programs. MSMEs lack access to skilling programs on new technology and future AI-skills	Medium Critical
C8	Due to globalisation and technology obsolescence, the products manufactured by MSMEs are not sustainable even for the duration of 10 years. This is the time required to repay the Bank loans. If the manufactured product goes out of market, how will MSMEs repay the loan ?	High The policy makers before introducing products should consider MSMEs
C10	Owing to the wage pressures from larger companies, skilled work force migrates to well-paying jobs in multinational factories near cities, leaving MSMEs in a constant churn of hiring and retraining[28]	High
C11	By implementing sustainability capability of Industry 5.0, MSMEs may not see tangible ROI	High
C12	MSME workforce's competency is low. There is skill-gap. There is a clear requirement for Upskilling	High
C13	R &D within MSME is very minimal or none. MSMEs can certainly benefit from the **Community R&D**	Medium
C14	Typically, in industries, production engineering department handles Process planning, Tool design, Production optimization, Quality improvement, Automation and efficiency. In MSME due to limited workforce and budget, they don't have a separate production engineering department.	Low
C15	MSMEs face many financial problems. MSMEs do not receive payment from their customers (buyers) within 30 days for the goods they have supplied.	High
C16	Currently, awareness about IPR is lacking in MSMEs IPR awareness is essential for MSMEs to protect their innovations, prevent imitation, and gain competitive advantage in the market. Also, it will help them	Medium

S. No	Challenges	Criticality(High /medium/low)
	manufacture IP protected products without getting into legalities.	
C17	MSMEs require upskilling on how to adopt AI and derive value from it to improve revenue, profitability and growth.	Medium
C18	MSMEs require support in the area of Cyber security as the awareness is low	High
C21	Many MSMEs still have legacy IT systems and legacy machinery which need to be upgraded The telemetry data such as machine status (running, idle, breakdown), energy consumption (kW, per machine), temperature, pressure, vibration, production counts, cycle time ,quality metrics are very useful. Since the legacy machinery doesn't support IIoT sensors, MSMEs are unable to collect these data	Medium
C22	For various industry sectors, there are not many published industrial case studies using either Industry 4.0 or Industry 5.0 technologies. The motivation amongst MSMEs in building new solutions is low.	Medium
C24	Many SMEs are still not able to get the data to forecast the demand (or production). This is because in many cases they cannot afford powerful server technology.	Medium
C25	MSMEs need to store the models what they had experimented, which failed. Instead of archiving them they simply delete. The reason they delete is because they don't have access to large storage system.	Low
C26	Most of the MSME work force don't get good trainings on future technologies. In particular they are not trained on Robotics for solving complex problems. Example: Robot based complex and precision welding of a windmill component They should be provided advanced Robotics training For this, MSMEs should be able to hire robots for complex tasks. No need for capital investment in Robots. Such robot-hiring for training will also enhance workforce efficiency and productivity	High it is a myth that Robotics replace workforce In reality the industries reshuffle the workers for different jobs within the organisation and impart training for those who can handle new technology

S. No	Challenges	Criticality(High /medium/low)
C27	Approximately in half of the T.N MSMEs, digitalization has not been done	Medium
C28	Identifying funding sources for industrial research and getting funds from those sources have been very difficult	High
C29	The MSMEs can't afford to invest time and money on strategic projects. MSMEs concentrate on current burning problems, and operational issues. They are concerned about ROI and they do not want to experiment.	High
C30	Many SMEs are still use and are comfortable with old legacy machines.	Low
C31	MSMEs are unable to invest capital funds in new technology projects. It is opex/rental/lease financial options only.	
C34	MSMEs lack quantifiable resilience metrics, real-time supply chain visibility, and demand intelligence, making them vulnerable to disruptions and unable to respond proactively.	High Govt should take step to create the above visibility and the MSMEs should know the customers and consumers their needs. Resilience based consultancy should be provided to MSMEs.
C35	Today China holds 30 percent of manufacturing and India is handling one tenth of it i.e. 3 percent This is because China started with labour intensive mode trained the workers whereas India failed to use the manpower properly and they relied on capital intensive mode.	Low
C36	Any operational problem or any raw material problems faced by MSMEs are not getting addressed in their neighbourhood or within the same region	High
C37	In the area of industrial technology, India / T.N academic institutions' focus is more on research, publications, and patents. Supporting and solving MSME technical challenges is not their priority.	Medium They should start measuring the

S. No	Challenges	Criticality(High /medium/low)
		employment generation through their Alumni connect
C38	MSMEs are unaware of where exactly the expertise available for solving their operational technical issues. This is a big challenge impeding the production. Academic Institutions on the other hand don't know the specific industrial problems for which MSMEs are looking for solution.	**Critical** MSME-academia collaboration is crucial. Each one should visit the other at frequent intervals Business models should be taught along with Engineering. New business models should be brought in. They should realise that by adopting technology They can get value added services and even the possibility of getting into a new vertical should be highlighted.
C39	Adoption of any technology involves huge cost. Any management is concerned about the ROI on Technology. Cost of the ownership of technology matters a lot whether industry 4.O or 5.O. Access to technology like access to funds is also a problem But, … Any management is concerned about productivity and hence to achieve productivity and increase the quality	**Critical**

S. No	Challenges	Criticality(High /medium/low)
	if they have to bring in technology which may replace labour, they may not hesitate to invest in technology Also … Many large OEMS insist on quality and they themselves spend on hardware and software for their suppliers who are operating in the range of Rs 100 to 150 crores. They do this to maintain quality and hence enhance the profit margins. So OEMS push their vendors for adoption of technology	
C40	Pradhan Mantri Kaushal Vikas Yojna (PMKVY) 4.0, is the flagship scheme of the MSDE. The scheme aims to empower youth by training them in industry relevant skills helping them secure decent employment opportunities. PMKVY 4.0,latest edition of the scheme, was announced in the last Union Budget with an aim to skill lakh of youth and provide training in courses on Industry 4.0, AI, robotics, mechatronics, IoT and drones. Case Studies have been published in [39]. There is no Case Study from Tamil Nadu. This indicates that PMKVY 4.0 might not have been fully exploited in T.N	**Critical** **Recommendation** Central Skill development programs should be fully leveraged by T.N MSDE should initiate a new program called PMKVY 5.0. This program should impart Industry 5.0 skills including Robotics, Digital Twins. Predictive Maintenance and Additive Manufacturing. All these skills with focus on Sustainability should be imparted.
C41	In the List of Government Institute for Training of Trainers (IToTs) offering courses under CITS, there is no Govt. Institute for Training of Trainers in T. N (CITS – Craft Instructor Training Scheme)	Low

S. No	Challenges	Criticality(High /medium/low)
C42	After purchasing machinery, many MSME units remain static for 10 to 15 years without meaningful upgradation.	Medium
C43	The understanding of Industry 5.0 was described as very limited, and even the understanding of Industry 4.0 was found to be incomplete in many firms.	High
C44	Defence sector raw-material procurement and certification challenge. In defence manufacturing and during the reverse engineering work, raw materials are often not freely available in India, and imports are restricted because the BIS certification is required. This was discussed as a major barrier for defence corridor industries trying to do R&D and product replacement work.	High
C45	Challenge: Banks do not usually give loans specifically for ERP adoption, so direct policy support is needed. Recommendation: government should create a subsidy or support scheme for ERP and digitalisation, similar to the old ISO 9000 support model. ISO 9000 support model was successful. when the government gave a subsidy of ₹75,000 for ISO certification, it helped many MSMEs understand quality systems and adopt standards.	Medium
C46	Three key challenges: 1.money, 2. skilled manpower, and 3. the ability to convert ideas into implementation. The point is that even if indigenous or other technology is available, the biggest obstacle is not the technology itself but the ability to finance it, staff it with skilled people, and move from concept to execution.	High
C47	Challenge: although there are many MOUs, the real value comes only when the industry's problem statements are actually taken up by academia and students. Examples were shared of colleges wanting their students to become industry-ready and of professors gaining exposure to actual industrial problems. A major concern in this section was the gap between college time and industry exposure. A three-year student spends around 1,000 days in college but only about 25–50 days in industry; an engineering student in a four-year course spends roughly 1,450 days in college but less than 50 days in	Low

S. No	Challenges	Criticality(High /medium/low)
	industry. The discussion concluded that this gap prevents students from understanding how industries actually function. To close this gap, the group discussed internships of at least three months, industry-linked problem solving, and stronger interaction between colleges and industries. Recommendation: After the primary internship, selected students would undergo short lab rotations in specialized areas such as robotics, CAD/CAM, AI, and machine learning. The idea was to identify the top 10% of students and give them multiple exposure points so that they do not remain with only one skill, but instead become multi-skilled and industry-ready.	
C48	Many MSMEs are unaware of existing government schemes .Tamil Nadu already has strong schemes, but utilization is low	Medium
C49	Challenge No structured documentation exists for: ESG adoption Human-centric practices Net-zero transitions Recommendation Immediate Action: • Build a Best Practices Manual include: • Proven models • Implementation steps • Cost-benefit clarity	Medium
C50	**Challenge** • MSMEs → Have problems but no access to experts • Academia → Has expertise but no real problems.	Medium
C51	**SKILL GAP – REALITY** • Not just lack of skills Problem is **implementation capability** **Gap Areas:** • Customization of tech • Deployment • Integration into existing systems	Medium
C52	The Industrial Housing Gap, is wide. Because of this,	High

S. No	Challenges	Criticality(High /medium/low)
	• Migrant workers lack affordable rental housing • Leads to high attrition and low productivity	
C53	Packaging Crisis • Excessive single-use plastic • No accountability Recommendation • Regulation + penalties • Sustainable alternatives	Low
C54	**Infrastructure & Energy** • Poor building design → long-term inefficiency • Over-dependence on cooling systems	High
C55	Today on account of globalisation instead of manufacturing only assembling takes place It was not so earlier. Due to this profit margin comes down Job work → Low margins → High competition → Replaceable supplier This will lead to commodity trap	High
C56	Products undergo changes quickly on account of technology. Technology Obsolescence Technology improvements take place without the knowledge of MSME and product longevity	Medium example from construction industry. Instead of earlier conventional method of construction now pre engineering construction takes place where steel is used for the outer shell and only in-between walls are used and this is

S. No	Challenges	Criticality(High /medium/low)
		fabricated outside and not at the construction site . This gives reduction in cost to 30 percent and saves time in the above example if MSMEs are not informed about the technology cement and bricks manufacturers will suffer
C57	Many technology pilots are successfully completed. However, industries are still facing challenges in implementing them in production[46]	Critical

Table 9: Challenges

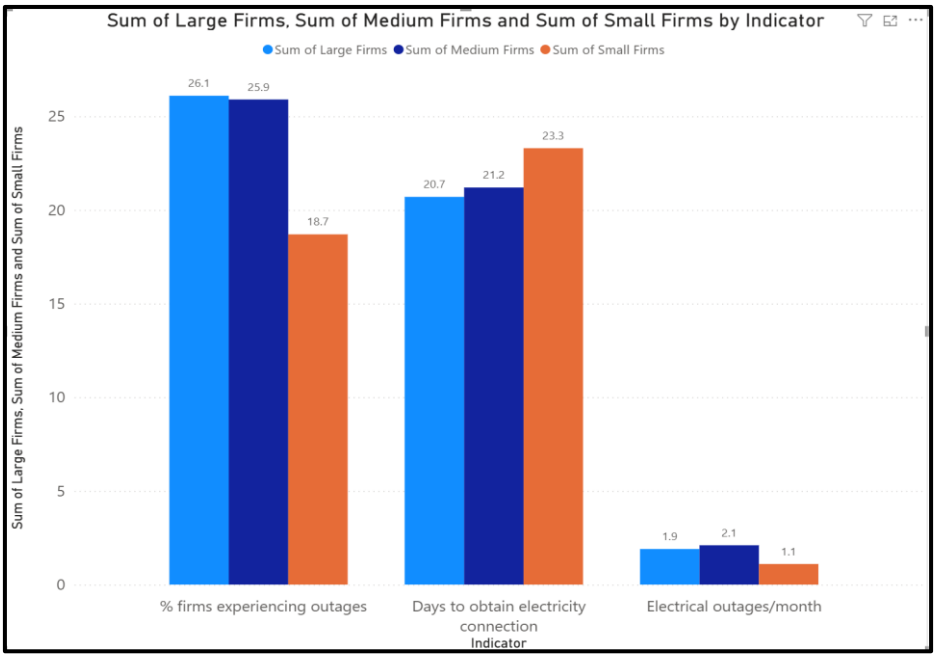


Figure 16: World Bank Enterprise Surveys 2022, www.enterprisesurveys.org

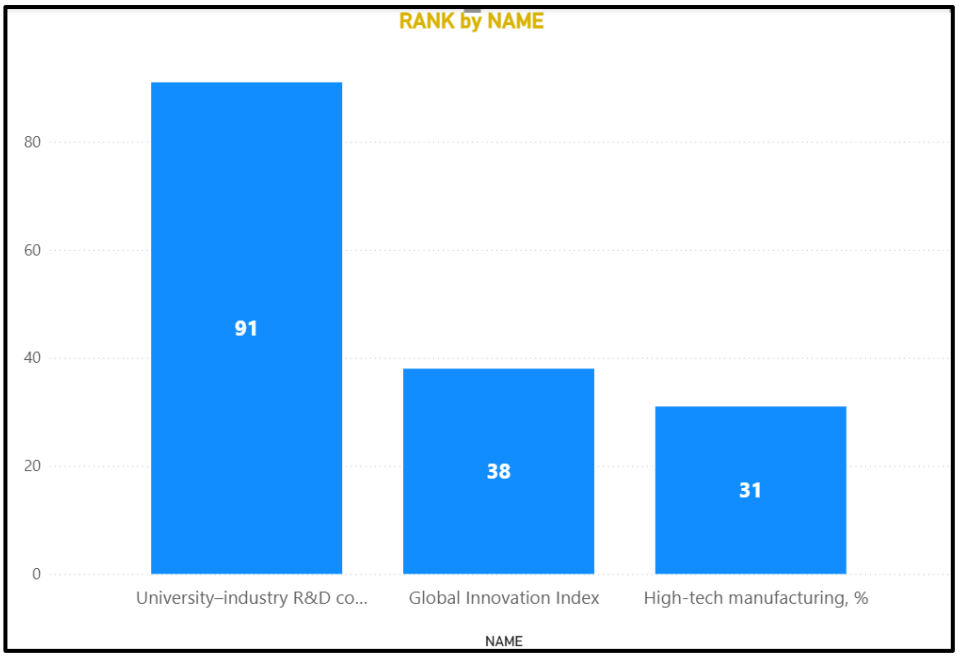


Figure 17: India’s ranking in Global Innovation Index 2025

13 Upskilling

According to NSDM[27] data, only 2.3 % of the workforce in India has undergone formal skill training as compared to 68% in the UK, 75% in Germany, 52% in USA, 80% in Japan and 96% in South Korea. We are facing alarming shortage of skills.



Figure 18: Upskilling sector specific skills (Image courtesy NSDM[27])

Reference [14] concludes that mastery of processes and equipment significantly influences manufacturing capability. It indicates that the achievement of manufacturing capability within the company is strongly influenced by the learning process within the company which is developed based on the resource-based view.

Type of skills required for MSME workforce

1.Sector specific manufacturing process specific skills

2.Industry 5.0 based future skills:

These skills are provided as part of India AI Future Skills - This program builds AI-skilled professionals. Support is provided to 500 PhD fellows, 5,000 postgraduates, and 8,000 undergraduates. Data and AI Labs are being set up in Tier 2 and Tier 3 cities[Reference 25].

Also, 'Naan Mudhalvan', another T.N state-wide skill development initiative that bridges the gap between education and industry by providing training in emerging technologies, career guidance, and placement support to students.

3.Sustainability related

see Annexure – A3 for Industry 5.0 sustainability skills trends

4.IP related

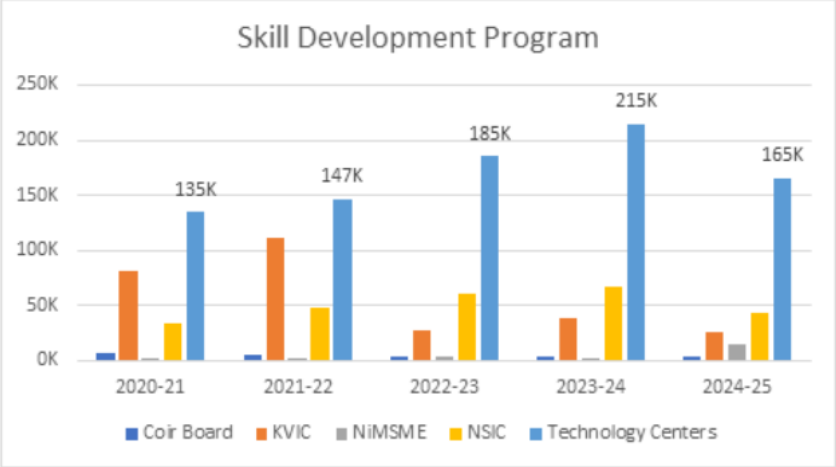


Figure 19: Skill Development Program

Best Practices for Upskilling

1. Choose Your Online Training Course Wisely
2. Balance synchronous learning(Real-time class room) with Asynchronous Learning(online)
3. Project oriented upskilling is must for industrial workforce

In 2024, the Manufacturing and Industry 4.0 brainstorming workshop at IIT Madras and was attended by many learned professors from various IITs. Importantly the group recommended several key skill development initiatives(see status report [18]) while simultaneously emphasizing the importance of Multi-Agency Collaboration for Skill Development. This report wholeheartedly supports rolling-out those recommendations.

14 MSME cluster – Engineering Colleges-Innovation Hubs

R & D and innovation are two capabilities, which if MSMEs acquire will take them up in the path to value creation. We are recommending innovation hubs at each MSME cluster. This will promote the culture of innovation amongst MSMEs.

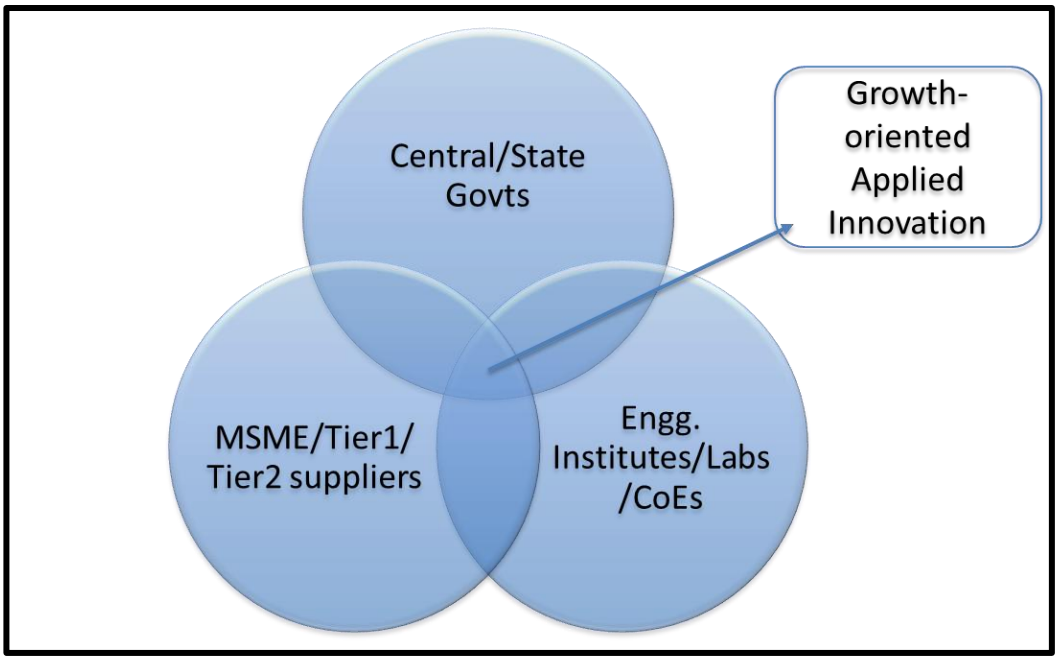


Figure 20: Cluster innovation hubs

15 Actionable Recommendations

As mentioned earlier, the audience for this report are (1). Central and State T.N Govt. ministries, and departments driving the MSME program (2). SMEs in T.N state (3). Leading labs in T.N working in the area of manufacturing, and technologies [see section 10.6 Centre of Excellence (CoE), and Research Centres in TN]. The actionable recommendations provided here in this report are targeted at the above audience.

15.1 Recommendations

No	Recommendations	Priority/effort	Additional comments
1	Tamil Nadu Govt. should setup and run community R&D centres in important MSME clusters such as Chennai, Coimbatore/Tirupur, and Virudhunagar. Respective regional engineering educational Institutes, CoEs, Research Labs, MSMEs, industry associations and T.N. Govt should play active role.	High/High	Some R&D centres can cater to more than one industry segments In the enclosed interview, one can hear the turmeric farmers representative asking Govt. to setup a research lab https://x.com/CNNnews18/status/2044096269740847176
2	MSME departments of Central/State Govts. should carry out skill census-exercise can comprehensively assess current skill levels across the state's regions and sectors. This will help map out the exact skills that are deficient and in line with industry demands at a granular level. With the help of the engineering institutes mentioned in section 10.5, 10.6, T.N Skill Development Department could offer training in digital tools, focusing on MSME workforce. Aggressively impart vocational and suitable Industry 5.0 technology training. Department could leverage Central Govt. Skill India program and other low risk program like NAPS.	Medium/ Medium	Low risk for MSMEs National Apprenticeship Promotion Scheme (NAPS) -On-the-job training Industry exposure

No	Recommendations	Priority/effort	Additional comments
	As part of the upskilling program, introduce completed Industry 4.0/5.0 solution case studies Industry-specific skill development should be the aim and not generic programs Set up an Industry 4.0/5.0 upskilling online portal containing training courses, completed solution case studies, workshops, webinars, tools and guidelines to strengthen MSMEs capacities to build Industry 5.0 solutions. Rich NPTEL engineering education portal https://nptel.ac.in/ should be integrated.		
3	MSMEs and industry associations should collaborate with engineering educational institutes to access expertise, resources, and shared knowledge in Industry 5.0. Within MSME, create a role called 'academic relationship manager' whose job is to enable collaborations. Concerned Govt departments should facilitate such collaboration. This relationship manager would play an important role in MSME-cluster-engineering colleges-innovation-hub Institutions like AICTE & Anna University could measure the effectiveness of engineering educational institutes participation and contribution to the MSMEs in collaborations	High criticality / Low effort	

No	Recommendations	Priority/effort	Additional comments
4	MSMEs should be provided training in the following Industry 5.0 Sustainability skills 1. sustainability reporting 2. renewable energy solutions. 3. energy generation and management 4. renewable energy procurement in alignment with climate goals 5. Energy efficiency 6. CBAM compliance 7. Case study [Reference 34 shows 17.5% energy savings] Central/State Govt. should provide subsidies for the first-time sustainability audit for CBAM compliance.	High/ Medium	Carbon emission reports must be verified by an EU-accredited independent auditor. Both direct and indirect emissions must be monitored March 31,2026 is the final deadline for importer to submit their applications to become an authorized CBAM declarant
5	Education department of the State Govt. in collaboration with the Engineering Institutes could offer two compulsory programs 1).short duration Industry 5.0 Certification program. 2).Design Thinking to Innovate. Every SME part of different T.N clusters should complete this training. This will enhance the awareness of Industry 5.0 amongst SMEs	Medium/ Low	List of participating Institutes are given in section 10.5 Dashboard monitoring of Certification completion is essential
6	Since Industry 5.0 requires a stable high performance IT infrastructure, Banks/NBFCs should offer financing support with lower interest rates specifically for Industry 5.0 upgrades.	Medium/ high	

No	Recommendations	Priority/effort	Additional comments
7	Individual MSMEs working in the defence manufacturing sector find it hard to navigate the certification and duty structure. They face BIS certification challenges. Hence the central government itself should procure raw materials and supply them.	High/ medium	Here, Govt. plays a role of OEM. It is common for OEMs to support manufacturers this way.
8	MSME leadership should organize training for its technology team on using India AI mission [25] compute-as-a-service. For Industry 5.0 workload MSMEs could leverage subsidized rates on Bharat AI mission	Medium/ low	Govt. to provide 10K GPUs to provide compute-as-a-service at subsidized rates for startup, researchers
9	At each T.N MSME cluster, institute an MSME-Academia innovation Hub. It is recommended that the concerned T.N Govt department oversees the progress and effectiveness. The MSME cluster–Engineering colleges-innovation Hub should publish Industry 4.0/Industry 5.0 case studies. Some publicly available sample case studies are shared in Appendix A6 The Innovation Hub should explore to benefit from ARISE-ANIC program This innovation Hub should explore collaboration with C-DAC which is inviting MSMEs to collaborate with them on innovation in disruptive technologies	Medium/ Low	See section 14 This will act as a catalyst and confidence building measure for leveraging Industry 5.0 for solving manufacturing problems The Aatmanirbhar Bharat ARISE-ANIC program(https://aim.gov.in/arise-overview.php) is a national initiative to promote research & innovation and increase competitiveness of Indian startups and MSMEs. The objective of Aatmanirbhar Bharat ARISE-ANIC program is to proactively collaborate with esteemed Ministries and the associated industries to catalyse research,

No	Recommendations	Priority/effort	Additional comments
	https://cdac.in/index.aspx?id=pdf_IoA_Collaboration_Innovation_V10 "Partner with C-DAC: A Call for Collaborative Innovation CDACINDIA is inviting an Intent of Association (IoA) from Startups, MSMEs, and Academia to co-create the future of Indian tech."		innovation and facilitate innovative solutions to sectoral problems. The objective is also to provide a steady stream of innovative products & solutions where the Central Government Ministries / Departments will become the potential first buyers.
10	Manufacturing industries can reduce the rejection rates by using Industry 5.0 (AI) based inspection, cobot-assisted precision assembly, digital twins, and real-time IoT monitoring to detect, predict, and prevent defects throughout the production process.	High/ High	Rejection rate is the percentage of products that fail to meet quality standards and are rejected during or after production. Example: Robot model ABB IRB 4600 image processor cabinets 3DQI Quality and Metrology cell Flexible holding fixtures, easy config of new parts using only CAD data and an inspection plan.
11	Leveraging Industry 5,0 technologies by MSMEs and building products for the international markets; MSMEs should also scale up to avoid missing opportunities.	High/ High	
12	**This recommendation is about a proposed quarterly MSME-Edu Industry 5.0 cluster workshop.** In this workshop, MSME leadership and leading engineering faculty can share and brainstorm MSME problems. How Industry 5.0 can be leveraged can be explored. Joint	High/ Low	Currently such interactions are happening in a more ad-hoc basis in some selective clusters. A sample tentative three hour **'Quarterly MSME-Edu Industry 5.0 cluster workshop' agenda** has been shared

No	Recommendations	Priority/effort	Additional comments
	Govt-agency(DST, DOS and others), CSR project funding can be explored. Example: In 2023, IIT Delhi (Chemical) - Research Facility Development for Conducted Research in the Field of Sustainability, Energy Generation and Storage and Novel Material Synthesis. Rs. 2.9 crores worth CSR contribution was used. Joint MSME-problem focused collaborations will be the outcome of this workshop. In the follow-on workshops, the project progress and outcome may be presented and discussed. Active involvement of Engineering institutes and MSMEs in specific clusters and close monitoring will ensure the success of this initiative. It is suggested that such initiative is initiated, facilitated, adopted, funded, implemented and monitored by joint-MSME-Education department of the T.N state govt.		This recommendation can be gradually developed along the lines of CII. https://cii-industryacademia.in/images/pdf/CII-Industry-Academia-Partnership-Compendium-2025.pdf [35] This is an excellent and successful program. But only very few tier 2 engineering institutes got involved. Particularly review the project. "Partnership between Pearson and Naan Mudhalvan" [51]
13	Make Industry 4.0/5.0 adoption covering ,automation, digitalization, mass production, sustainability, resilience, and improving the overall quality of life of the industrial workforce as a national mission like , Swachh Bharat(Clean India) and like the COVID vaccine rollout, pushing the entire supply chain.	High/ High	Not just a slogan but a National Mission with funds, governance structure and dashboard to monitor.
14	Within the existing legal framework and regulations,	High/ High	CSR – Corporate Social Responsibility

No	Recommendations	Priority/effort	Additional comments
	expand the scope of CSR to cover large number of educational institutions and to many industry-growth-enabling-technologies		Under the Companies Act, 2013 (Section 135 + CSR Rules): • CSR spending must go toward activities listed in **Schedule VII** (education, skill development, etc.) • CSR **cannot be a normal business benefit** or purely profit-driven support
15	The CII Industry–Academia Partnership program[35] has been one of the successful and model programs enabling collaboration between Industry and Academia across India. Create more such programs to enable Industry and Academia. Involve MSMEs and more Tier 2 Engineering Institutions, in addition to IITs, IISc. These institutes can collaborate with T.N MSME clusters spread across but not limited to Krishnagiri, Ranipet, Virudhunagar, Trichy, Kanchipuram, Tirupur, and Tiruvallur.	Medium/ Medium	
16	• **Holistic skill development model:** Train the workforce on in industry solutions and complementary skill combinations such as CAD-AI-ML-IIoT-Cybersecurity-robotics, and power-train - EV- Lithium-ion battery management. Also include PCB and sensors, mechanical systems, AI and data analytics, robotics integration, EV and Lithium-ion battery systems, solar energy systems,		

No	Recommendations	Priority/effort	Additional comments
	and semiconductor-related training. • Each cluster would be linked to a CoE or Innovation-Hub and a short training duration. • There is a need for a formal project roadmap and a detailed project report. The plan included district-wise mapping of MSME clusters, identification of skill gaps, Cluster-innovation-hub, • Funding model is required.		
17	Central and State Govt. of T.N together have many good schemes for MSMEs. But many MSMEs are unaware these schemes Tag and layer the schemes as *Housing,* *Skill development,* *Technology upgradation funds,* *Sustainability* Recommendation is to Create bundled value by integrating all the Schemes		
18	1. TN Govt should Establish "Green Export Corridors" 2. Launch the "CBAM Readiness Fund" 3. T N Should issue "Industry 5.0 Skill Vouchers" for MSMEs Transitioning to 5.0 requires workers who can collaborate with "cobots" and manage ESG data. * Voucher System: Provide MSMEs with "Skill Vouchers" that can be redeemed at	High	What is CBAM ? The EU Carbon Border Adjustment Mechanism (CBAM) is a climate tool placing a carbon price on carbon-intensive goods (steel, cement, aluminium, fertilizers, electricity, hydrogen) imported into the EU to prevent "carbon leakage"

No	Recommendations	Priority/effort	Additional comments
	recognized institutions (like IIT Madras or Anna University) to upskill their existing workforce in Human-Machine Collaboration and Life Cycle Assessment (LCA). 4. To prevent MSMEs from being overwhelmed by paperwork, the Ministry of MSME should integrate carbon tracking into the Udyam Portal 5. **Carbon Credits & Government Policy Recommendation** MSMEs adopting sustainability and Industry 5.0 practices should receive green credits translating to tangible benefits — preferential tax brackets, subsidies, or grant eligibility		
19	Integrate **Pradhan Mantri Awas Yojana (Urban)** with state-level initiatives such as the **Tamil Nadu Infrastructure Fund Management Corporation (TNIFMC)**, By implementing this recommendation, Tamil Nadu can unlock the potential of **industrial housing**. This approach addresses the **critical shortage of safe, affordable rental housing for industrial workers**, thereby improving workforce stability, productivity, and overall industrial competitiveness. • Stable workforce • Reduced labour turnover • Better living standards → higher efficiency	High/ High	This recommendation is based on a News article on this subject. We have connected it to Industry 5.0

No	Recommendations	Priority/effort	Additional comments
	Importantly, by doing this, the wellbeing of the workforce gets more importance which is one of the important philosophies of Industry 5.0		
20	Create an interface between the MSMEs and the policy makers. This will help MSMEs to change their business lines, protect their assets and adopt new technologies	Medium/ High	
21	Directorate of Industrial Safety and Health(DISH) should do a survey of industries which could possibly get accidents like boiler explosion. DISH should strongly recommend industries to implement strong monitoring capabilities. For large factories, DISH should suggest implementing predictive maintenance and digital twins based monitoring solutions to prevent any boiler explosion accidents.	High/ High	
22	Textile is a massive industry in Tamil Nadu. Highly energy and resource intensive — even a 5 – 10% reduction in OpEx delivers significant margin improvement. Enables competitiveness even under higher tariffs (e.g., US trade pressures) It is recommended to run a dedicated Industry 5.0 research programme targeting textile industry, possibly anchored at Tiruppur.	High/ High	
23	Along the model of WSC, Bhubaneshwar, start T.N World Skill Centre (TNWSC) with international collaboration. Institute this as a section 8 company so that it is eligible for CSR funds. TNWSC should focus	High/ High	

No	Recommendations	Priority/effort	Additional comments
	on manufacturing skill development in the focus-sectors such as automobile, Chemical, Precision Engineering, Casting, Textiles, Food Processing, Defence Manufacturing and Fire Works. TNWSC should have State-of-the-art facilities and cutting-edge technologies in the area of manufacturing focus-sectors . TNSC can follow the hub and spoke model, With TNSC as the Hub and all ITIs & Polytechnics in T.N as Spokes TNWSC should offer • Industry oriented training courses • High-quality skill development programs • Practical learning and hands-on knowledge and values required by the industry • Technical and vocational education and training • The trainings may be offered in three levels • Level 1- Foundational • Level 2 – Deep skills • Level 3 – Industry 5.0 skills • Conduct T.N Skills Competition • Train the Trainer (ToT) Post the successful training students should be able to do internship in organizations outside India		
24	**MSME resilience framework** should be created for enabling: • Quantification of resilience through standardized metrics	High/ High	

No	Recommendations	Priority/effort	Additional comments
	• Real-time supply chain visibility via digital platforms • Structured resilience consulting and advisory support		
25	Create a “Go-To Manual” Govt. Schemes available for MSMEs. mapping How to apply? What documentation required ? How to combine schemes for max benefit?	High/ low	
26	MSMEs should aspire to shift from manufacturing-only to the following RDIM working model 1. R&D / Innovation(R) 2. Design(D) 3. Integration(I) Combining multiple parts into a system or solution 4. Manufacturing(M) Execution engine		IIDM Strategy: Foxconn MD Terry Gou championed "Integrating Innovation Design Manufacturing" (IIDM) as the future of the company. 1.Benefit: Creates intellectual property (IP) or unique know-how Moves MSME from “supplier” to “problem solver” Example: Instead of just machining parts, you develop a new mechanism or process 2.Benefit: This is where value multiplies Whoever owns design often controls pricing and customer relationship Example: Designing a full sub-assembly instead of just one component 3.Benefit: Customers prefer fewer vendors & higher stickiness

No	Recommendations	Priority/effort	Additional comments
			Example: Delivering a complete module, not 10 separate parts
27	Consortium-Based Funding Model is recommended (Recommendation by Dr. Raghavendra Prasad) ○ Industry contributes → "skin in the game" ○ Government supports ○ Academia executes ○ **Output:** ○ Practical solutions ○ Shared IP (with priority access to contributors) ○ **Important Shift:** ○ Move from "discussion-based collaboration" → "funded, milestone-driven execution"	High/ High	
28	" You earn the right to tell your story, when you start with theirs " - Matt Heinz, President of Heinz Marketing Instead of leading MSME conversations first with technologies /jargons • Industry 5.0 • AI • Cobots • IIoT • Digital Twins lead the conversations first with MSME's own problems, REAL LIFE CASE STUDIES and benefits	Medium/ Low	

No	Recommendations	Priority/effort	Additional comments
29	Usher in Behavioural Change in MSMEs towards cybersecurity by a. Creating mass awareness campaigns with local language support based on MSME size and technology dependence/maturity (layered approach) through continual programs with repeated messaging using multi-modal out-reach approach. b. Use-Case based Trainings (themed common attacks eg. Payment frauds, E-mail frauds ransomware attacks, deepfake scams, employee digital frauds, IT vendor frauds etc.) targeting Cybersecurity Trainings for MSME boards/governing body/owners and functional leaders with suitable outreach strategies Identifying Key focus areas for MSMEs based on Business Impact Cybersecurity Assessments, Identity security (MFA), Backup & recovery, Payment fraud controls, Vendor risk management, Incident response readiness c. Work with agencies such as TN (TN Cybersecurity Policy, TIDCO and ELCOT) and Meaty, CERT-IN, MHA,DSCI to create the baseline Framework for minimal MSME Cyberseucrity that can be comfortably adopted by any MSME supporting sector specific Industry 4.0/5.0 (AI, IoT, SCADA, Robotics etc.) requirements. d. Certified Cybersecure MSME Units : Work with Government to issue guidelines for Greater Recognition of	High/ Medium	

No	Recommendations	Priority/effort	Additional comments
	Certified Cyber-Secure MSME Units in Procurement/allotment of orders e.g. GEM Portal etc. for Certified Cybersecure MSME Units. i. Work with Government to give greater recognition/score to MSMEs that are certified for Good Cybersecurity based on Audits. ii. Work with Government to issue directions mandating Cybersecurity certification as a pre-condition to PLI and other Incentives, major procurement orders and tenders, pre-condition to Finance from Banks iii. Simultaneously work with Private Sector to mandate and give preference to Certified Cybersecure MSME Units in all procurements. Create MSME Sector Specific Cybersecurity Clinics with Government Grants and CSR: Provide digital support infrastructure for supporting MSMEs with cybersecurity advisory, imply emendation support, cybersecurity Incident handling support and response, On-Demand cybersecurity assessments, DPDP Implementation Support		
C30	Undertake technology pilots with a very clear plan to roll out in production. If the production deployment of the pilot is not ascertained, then	High/ Low	

No	Recommendations	Priority/effort	Additional comments
	the pilot should not be given high priority,		

Table 10: Actionable Recommendations.

16 Planned Future Work

Wave 1/Phase I

The research and analysis carried out in this report is Wave 1. In wave 1, our findings are high-level and based the wisdom of industry leaders and our own literature survey

Wave 1/Phase II

In this phase, we will work with central and state authorities and other stakeholders mentioned to roll out the recommendations documented in Wave 1/Phase I

Also, in this phase we will do some pilots to demonstrate the feasibility and effectiveness of the recommendation. For these pilots, we will collaborate with CoEs and Institutes mentioned in this report

Wave 2/Phase I

in the next phase of the research, we plan to consider a high-priority sector, say textiles or matches/fireworks/off-set printing or auto components. We will follow a data-centric research approach. We will do detailed data collection and use Data analytics/AI to uncover more insights into the data.

Wave 2/Phase II

In this phase, we will work with central and state authorities to roll out the recommendations documented in Wave 2/Phase I

17 Key Take-aways

- Industry 5.0 is a combination of enhancements and extensions to Industry 4.0 to address the latest demands, trends and developments in society, environment, business and technology.
- Growth oriented applied innovation will be possible when MSMEs – Engineering educational institutes – Govt. come together through innovation Hubs. Leading manufacturing countries have been following this approach successfully. Industry-academia collaboration is not only aides in research but also in skill-development.
- We strongly believe SMEs, Tier1, Tier 2 manufacturers in T.N and in other states can move up in the value-chain by gradually implementing the industry 5.0 solutions following the attached indicative roadmap provided in section 10.4.2, Figure 12.
- In order to create the intellectual property (IP), to controls pricing and customer relationship, MSMEs should aspire to shift from manufacturing-only to the RDIM working model

  R&D / Innovation(R)

  Design(D)

  Integration(I)

  Manufacturing(M)

- If technology is viewed only through the lens of cost, adopting Industry 5.0 will be slow. Instead, it should be positioned as a creator of value.

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Annexure – A1

Interview Questionnaire

As part of this study, we interviewed many experts from the industry. Such expert opinions are an integral part of this report. The interviews with experts covered the following topics.

No	Topics	Remarks
1	What is your point of view about various Industrial Revolutions like 3.0, 4.0 and 5.0 and their applicability/relevance to Tamil Nadu MSMEs?	
2	Which amongst the following MSMEs are likely to benefit more from the industry 5.0 principles? Industrial Goods/machinery Textile/Garments Automobile Precision equipment Chemical Defence Fireworks	
3	What is the current level of maturity of adoption of T.N MSMEs of Industry 3.0/4.0/5.0 principles?	
4	What are the main inhibitors for TN MSMEs to adopt Industry 5.0?	
5	The main technologies as part of Industry 5.0 are AI, Robotics, IoT, automation, Additive Manufacturing, 3D printing, Digitization, and Cloud. Which one or two of these technologies are most relevant to MSMEs?	
6	Within an MSME which Unit or department is competent/responsible for deciding on Industry 5.0 adoption?	Promoter/investor
7	Where do MSMEs prioritize their investments ?	
8	One of the challenges faced by MSMEs appears to be shortage of manpower. Do Do you think, Industry X.0 initiatives will help or do you think it will aggravate manpower-shortage issues?	
9	What is your long-term vision for the MSMEs in the context of adopting Industry 5.0 as part of their growth strategy?	
10	Have you come across any authentic report on this topic, which you want us to review?	
11	Like we interviewed, do you strongly feel, we should also interview another authority on this topic?	
12	Any other information you want us to know which we have missed discussing?	

Table 11: Interview Questions

Annexure – A2

Government's effort to strengthen the MSMEs

Press Information Bureau
Government of India
Ministry of Micro, Small & Medium Enterprises
04 FEB 2025 5:27PM by PIB Delhi
Budget 2025-26: Fuelling MSME Expansion

Credit access, digitisation, and business-friendly reforms lead the way

Introduction

The Union Budget 2025-26 introduces a series of measures aimed at strengthening the Micro, Small, and Medium Enterprises (MSME) sector, recognising its role as one of the key engines in India's journey of development, alongside agriculture, investment, and exports. To help businesses expand and improve efficiency, the investment and turnover limits for MSME classification have been raised. Access to credit is set to improve with an increase in the credit guarantee cover for micro and small enterprises, startups, and export-focused MSMEs. A new scheme will provide financial support to first-time entrepreneurs from disadvantaged backgrounds, while sector-specific initiatives will enhance productivity in areas such as footwear, leather, and toy manufacturing.



As a vital contributor to India's industrial landscape, the MSME sector plays a crucial role in manufacturing, exports, and employment. With 5.93 crore registered MSMEs employing more than 25 crore people, these enterprises generate a significant share of the country's

economic output. In 2023-24, MSME-related products accounted for 45.73% of India's total exports, reinforcing their role in positioning the country as a global manufacturing hub. The new budgetary provisions aim to build on this strong foundation by fostering innovation, enhancing competitiveness, and ensuring better access to resources. Through these steps, the government seeks to equip MSMEs with the tools needed to expand their reach and strengthen their contribution to India's economic growth.

For further details, visit the following link

https://www.pib.gov.in/Pressreleaseshare.aspx?PRID=2099687&utm_source=chatgpt.com&reg=3&lang=2

Annexure – A3

Industry 5.0 sustainability skills trends

Over the past year, the skill of sustainability was among the fastest growing in the technology industry

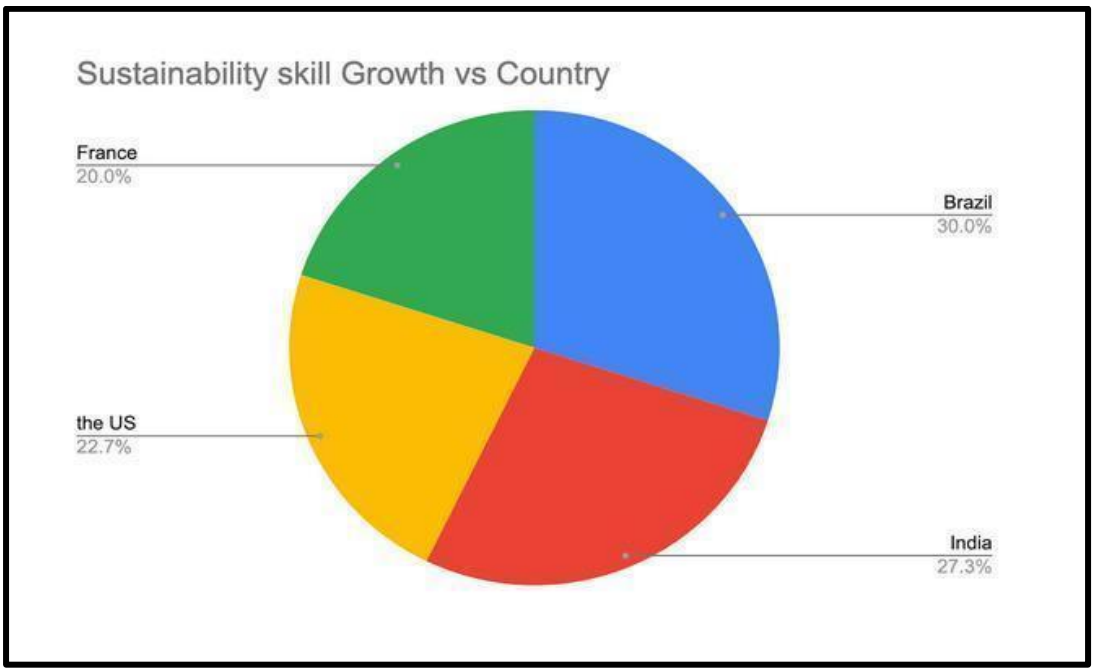


figure 21: Sustainability skill Growth Vs Country

Sustainability skills

1. sustainability reporting
2. renewable energy solutions.
3. energy generation and management
4. renewable energy procurement in alignment with climate goals
5. Energy efficiency

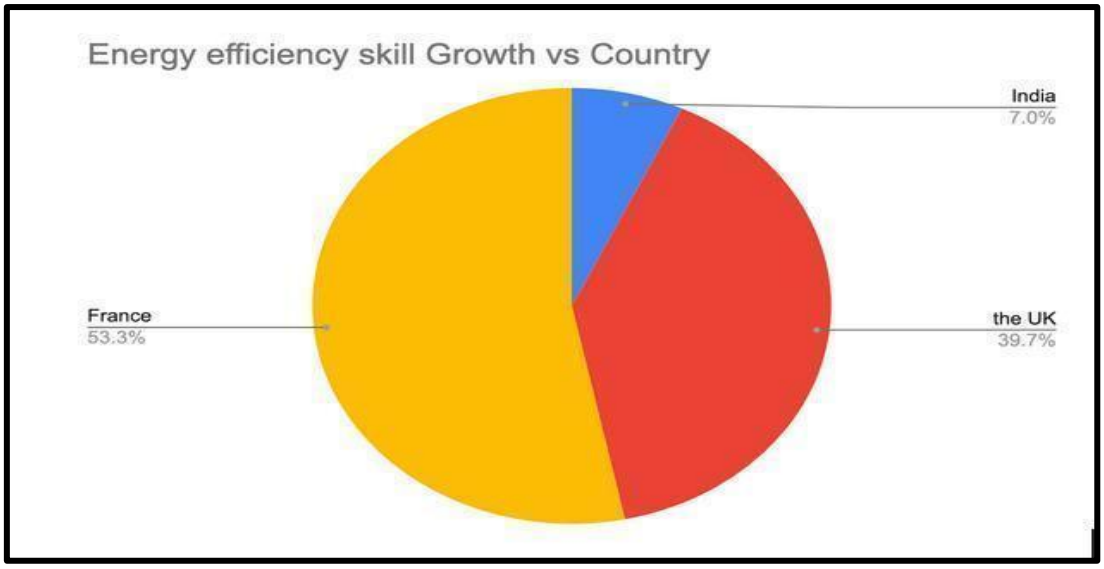


Figure 22: Energy efficiency skill Growth vs Country

Annexure – A4

Classification of enterprises

- An enterprise shall be classified as a Micro, Small or Medium enterprise on the basis of the following criteria, namely:
- a micro enterprise, where the investment in plant and machinery or equipment does not exceed one crore rupees and turnover does not exceed five crore rupees;
- a small enterprise, where the investment in plant and machinery or equipment does not exceed ten crore rupees and turnover does not exceed fifty crore rupees; and
- a **medium enterprise**, where the investment in plant and machinery or equipment does not exceed fifty crore rupees and **turnover does not exceed two hundred and fifty crore rupees**

~https://rbi.org.in/scripts/FS_Notification.aspx?Id=11934&fn=2754&Mode=0

Annexure – A5

Minutes of the meeting / Interview Notes

Interview 1, Minutes of the meeting, 16-01-2026, 3 PM, Prestige Bella Vista

Person who was interviewed

Mr Srinivasa Raghavan

General introduction about SSS the purpose of study topic chosen under industry 5.O was briefed to him

The following inputs we received:

He started the discussion with emphasis on Micro industries in Sivakasi belt

Then it was made clear that we would take medium industry for study at the beginning and then will go deep into particular cluster

According to him AI will certainly decrease the manpower utilisation.

In health care industry particularly in US and UK there will be unutilised resources down the line on account of AI.

Reverse Brain-Drain: Hence when they migrate here their quality will be high compared to the local m…

MSMEs have scope

Automobile ancillary parts EV is given thrust in the areas of Robotics and IOT scope for innovation for MSME

Also, non-conventional power

Solar

Nuclear

MSMEs can play a role.

Thermal Coal based will die out soon

MSMEs have scope in Batteries manufacturing.

14) Tier 2 and Tier3 cities infrastructure should be developed. Connectivity should be improved so that they set up units there. It will help utilisation of manpower and improve production in those areas

15) **There could be a challenge for Pharma industry on account of IP issues**

16) Also, drug industries there are changes in formulas say single chemical is recommended it will die down the line

17) MSMEs are prevalent globally.

In Asia China MSME plays a great…

Sir hope I have included all the points

Small doubt 1 crore will come down by 50 percent revenue or labour force

I have noted down labour force

Also, in industry 5.O there is a trade-off between human centric factor and sustainability factor.

Interview 2, Minutes of meeting, Tuesday and Wednesday, 20 and 21 Jan 2026, 3:00 PM.

Person who was interviewed

Meenakshi Sundaram

CTO, Amalgamation,

Mount Road, Chennai.

1 Mr Meenakshi Sundaram shared the following inputs

According to him R&D requires huge amount and not all companies can do

2 In industry 4.O only automation and not human centric and industry 5.O human intelligence do better .However MSMEs do not even in 4.O and it is either at 2.O or 3.O

3 The situation is different in Vietnam or U K

4 Most of them handle semifinished goods and have individual process stations

5 He analysed into three categories

Man, Machine and Money and since they do not get back ROI, they are not in 5.O

6 MSMEs should enhance the productivity only two shifts they work maximum

7 Competency is another challenge .Skilling is required

8 We have moved into EV without R&D product development

Only assembling

9 No engineering in EV

10 In general only Integration is happening and not R &D .There is no production engineering department in Micro and Small

11 The small companies face lot of financial problems They do not get payment for raw materials within 30 days

12 Hence responsibility increases and profitability comes down

14 According to him automation has changed the job description and not moved the jobs

15According to him industries at Tier 1 level can adopt easily automation.

They are more than medium industries

This is his new insight for defining the industries

16 Tier 2 level we can push automation and economic pressures can bring in

17 He said each industry should analyse how much industry 4.O and how much 5.O

18 His own experience introduction of Robots has not replaced labour but extra jobs created for maintenance of Robots

19 Manufacturing industries can reduce the rejection rates by adopting industry 5.O

20 According to him India is capable of adopting industry 5.O.

We should classify that is Indian classification of. industry 5.O should be there

21 He classified industries into 4 quadrants

1 Complexity and both volumes are low

2 complexity is high volume low

3 complexity is low and volume high

4 complexity and both volumes are high

22 First one not useful

Second one ROI will be less

Third one we can push as ROI will increase

Fourth one of course it is easy for adoption .

Other points his own experiences.

Interview 7, Ashish Khushu Minutes of the meeting, 2-2-2026, 2.30 PM, Gmeet

Person who was interviewed

Ashish Khushu, CTO, LTTS

[12:43 am, 3/2/2026]

1) Basically, they help industries to design and develop products and to set up plants green plants etc

2) According to him we should talk which is relevant to them

Whether it is 4.0 or 5.0

3) The MSMEs are averse to jargons.

They have streamlined operations and assembly lines

Systems

Automation

Electronics Robotics are used.

They are not behind they use SCADA, ERP etc, cutting edge technology for them means a different protocol

4) what is industry 4.O Digitalisation It has very huge connotation think what we can add

Application of machine working can be transferred to an app in mobile Or Digitising records

Data consolidation is another step

5) 4.0 digitization means different depending on the granularity of different areas.

6) For example, why should they opt for cloud If a server can do the work

7) If industries are not up to 3.0 then 4.0 will fail Analog. UPI will work only if you have money in the bank 4.0 is nothing but digitization on top of 3.0 and hence 5.0 is at a different level even mature organisations are finding difficult for sustainability

8) in the case of EV, it was predicted that it will run 200kms only after charging but it is running 500 kms but only 30…

Summary

Do not use jargons

Study whether they are 3.O complainant

Recommend only if it benefits

Some industries can adopt as the OEMs can push and they have templates

Community R & D may not work

Awareness about IPR is essential for MSMEs

Colleges can serve as nodal points for R&D for nearby MSMEs and clusters should be formed around the colleges

The CSR should be allowed for investing in R&D at tier2 and tier3 cities

Interview 8, Satyanarayana Venkatraman Minutes of the meeting, 3-2-2026, 10.30 AM, Online

General introduction about SSS the purpose of study topic chosen under industry 5.0 was briefed to him

Comment: Medium enterprises are not even 4.0 why are we jumping to 5.0, Rather than concentrating on 5.0, why not analyse 4.0

MSME challenges: credit demand, cash flow are problem, no formal loans

MSME challenges: very high Skill gap – no formal certification – can cause trouble

Input on AI: The NASSCOM survey says that there is potential for AI within MSME. But MSME is unaware of how to adopt AI and derive value out of it to improve revenue and growth

Challenge: MSME doesn't have manpower for working on Industry X.0 strategies within MSME

Sathya's Recommendation: Institutes like IIT M, VIT, SRM can impart training on various technical areas and specifically on applying Industry 4.0/5.0 for MSME operations

Challenge: Cyber security awareness amongst MSME is very low

Challenge: Basic (technology?) best practices are not followed within MSME

Suggestion for the Research: Collect cluster specific data samples by conducting a cluster specific interview with a MSME tech thought leader

Related information provided: VIT runs MSME workshops. VIT has a very good Robotics Lab,

Interview 9, Dr. Prakash, Minutes of the meeting, 5-2-2026, 10.30 AM, Eswari Engineering college,

Industry 5.0

1) Transportation
2) Logistics / fleet management sys
3) Legacy systems upgrade : Upgrade of legacy systems at SME factories is strongly recommended
4) The telemetry data is very useful and important for manufacturing organizations. But the irony is SMEs are not getting Data that is useful to them. That is the reason why, SRM is helping SMEs to gather IoT sensor-based data.
5) There are not many Industrial use cases of Industry 4.0 technologies?
6) Who are you interfacing with is MSME?
SRM team only interfaces with Maintenance team. But we are interacting with manufacturing team, and Promoters of SMEs.
7) We don't talk to them on high-level tech jargons/lingos instead we talk to them about their problems and challenges. It makes the discussions meaningful
8) Based on our understanding the Trichy SME cluster is focussed on wind mill and on welding technologies. Trichy BHEL is known for Boiler technology
9) In our view the top most Industry 4.0 technology is
1. IOT
10) In our view the topmost SME cluster is
2. Chennai Sipcot

1) Transportation is the problem Lack of infrastructure. Poor roads as the units are situated outskirts.

2) Fleet management system is a problem. Logistics cost plays a huge role

3) They use Legacy machines. Upgrade the existing machines and do not invest in new machines to avoid capital outflow. This is a major constraint for adoption of new technologies

4) Data collected by them is historical data. It is used for the manufacturer of the equipment or machinery used by them. For example, sensors in machinery do not give data relevant to the business or company and it captures data about the machinery. As far as digitization is concerned, they do not have bandwidth to purchase hardware or software.

5) They are not able to get data to forecast demand or production as some cases they cannot afford servers also

6) Another issue data storage system

7) MSMEs require references and copy the models If they do not work, they simply delete

8) 70 percent of MSMEs in automobile vertical have the above bottlenecks.

9) Dr Prakash explained about their COE for Industry 5.O

They collect the problem statement from the industry and provide solution The institution has the Virtual experience centre. They develop POC and give it to the customers.

10)For example, in Nokia centre other customers are allowed to experience the solution with synthesised data.

11) when we asked about the patent, he said patent is owned by the college as they innovate and hence it does not belong to the customers.

12) They provide solutions and do not sell the patents

13) The customer can get the experience with synthetic Data

14) According to him in medium and large industries industry 5.O adoption is there only to a limited extent

15) He said that it is a myth that Robotics replace men

16) In reality the industries reshuffle the workers for different jobs within the organisation and impart training for those who can handle new technology

17) MSMEs should be encouraged and taught to handle Robots for complicated things

18) He gave an example of usage of Robo in welding where it involved precision and complexity. Windmill component

19) He suggested that MSMEs should be in a position to hire robots for complicated things which will also enhance efficiency and productivity

20) He advised us to cover one or two more districts like Trichy Coimbatore

21) All over India according to him the following verticals can adopt 5.O

FMCG

Automotive

Process industries

22) MSMEs should concentrate or add value in process development not product development. That is, they should be asked to innovate

23) Make in India scheme has helped for the above to a certain extent as reverse engineering has developed.

24) However, for technical know how we still depend on outside

25) According to him in Tamil Nadu in manufacturing 50% not yet digitization done

26) There are huge funds available for research but remain unutilised and thrust for R&D is a must

27) Research institutions should provide solutions for the industrial needs

28) Integration of solution with innovation should be promoted

Interview 11, Minutes of the meeting, 6-2-2026, 3.00 PM, IIT Madras

Person who was interviewed

Prof R. K. Amit

1There is no clarity on the definition of industry 4.O It is assumed that AI means Chat GPT They do not think beyond.

2 There is no consensus about definition and for that matter even industry 3.O is not defined and it varies as defined by UNIDO and Germany etc

3. The SMEs do not think of large problems.

4. Concentrate on current problems. Operational issues. Concerned about ROI and they do not want to experiment.

5. The SMEs are comfortable with old machines.

6. Small example related to tiny sector for pressing clothes many use coal for iron box.

7. So, suggestion is we should adopt pull theory and not push theory.

8. Democratisation of technology is the need of the hour

9. MSMEs should not invest capital for technology it should not be a capital expenditure.

10. It should be only Opex .

11. He spoke about sanitization. Function of the product to be sold and not the product. Government or other professional bodies should collaborate for this. SMES should be taught about scaling up.

12. New business models should be brought in. They should realise that by adopting technology They can get value added services and even the possibility of getting into a new vertical should be highlighted.

13. Important point is we should quantify Resilience to MSMEs.

During covid there were disruptions in supply chain and many of the medium companies were not aware. It was not visible.

MSMEs should become part of the supply chain.

14 Govt should take step to create the above visibility and the MSMEs should know the customers and consumers their needs. Resilience based consultancy should be provided to MSMEs

15.Even today China holds 30 percent of manufacturing and India is handling one tenth of it i.e. 3 percent

16 This is because China and Japan started with labour intensive mode trained the workers whereas India failed to use the manpower properly and they relied on capital intensive mode.

17 In China any problem by any manufacturing company is solved within 5km radius. Example how the manufacturing of Lithium-ion battery for phones started in China

18. In India the academic institutions worry about research patent etc Not bothered about employment generation.

19. They should start measuring employment generation by Alumni

20. Industry academia collaboration is crucial Each one should visit the other at frequent intervals

21 He spoke about the smiling curve where simple manufacturing lies at the bottom of the curve and design concept Integration lies at the top

22 MSMEs should also be taught about moving to design stage and not simply manufacturing.

Example Foxconn and Apple why these two are at different levels

23 According to him Automobile chemicals can benefit from automation and adoption of technology

24 MSMEs should be taught about the usefulness of digitization and there is no point if it is implemented simply.

25 Business models should be taught along with Engineering.

26 He said it has to align with the use case Formula 1 car cannot be used and no need to learn about its Engineering

27 He also spoke about Economies of unscaled and emphasized the need for scaling up of the business of MSMEs and creating awareness about it among them.

28 Referred two more leaders

Interview 12, Ms. Shobana Ravi ,Minutes of the meeting, 12-2-2026, 4.00 PM, TAFFE

General introduction about SSS

1 Adoption of any technology involves huge cost. Any management is concerned about the ROI on Technology. Cost of the ownership of technology matters a lot whether industry 4.O or 5.O.

2 According to her access to technology like access to fund is a problem

3 Industry5.0 collaborates people and technology but collaborating among people itself is a problem here

4 Any management is concerned about productivity and hence to achieve productivity and increase the quality if they have to bring in technology which may replace labour, they may not hesitate to invest in technology

5 However the access to technology for small players is less

6 She suggested a model that technology should be provided to the MSMES by the government…

11 Many large OEMS insist on quality and they themselves spend on hardware and software for their suppliers who are operating in the range of Rs 100 to 150 crores. They do this to maintain quality and hence enhance the profit margins. So OEMS push their vendors for adoption of technology

12 She said adoption of industry 4.O or 5.O where automation and digitization are a must should become a nationwide movement

13 She gave COVID vaccine as an Analogy. How it became a movement how the entire supply chain was given a push similarly the vendors in the supply chain should also be pushed for adoption of technology.

14 It should be a collaborative effort of Govt industry academia.

15 As the MSMES have problems in accessing funds technology and also security…

17 As far as MSMES are concerned they should be prepared for adoption of technology. Product scaling up and new product development should be taught and awareness to be created by workshops seminars etc and there are a few MSMEs who invest in R&D

18 She said Tier I MSMES cater to multiple OEMs and hence they will easily adopt technology but others if they have to remain or sustain in the supply chain, we should inform the benefits

19 We should build products to cater international markets. If we do not adopt technology and scale up as we have missed the Bus. in AI like how east India company dominated us we are likely to be dominated by any AI company.

20 Government should have a think tank sitting on top of this and push towards this.

21 The issue is very huge, and gigantic movement is essential to bring about awareness and handle change management.

22 Like Swachh Bharath it needs to be a nationwide movement

{Classified version of Minutes follow:

Challenges and Barriers

● Adoption of technology involves high costs, with management focused on ROI and total cost of ownership (e.g., Industry 4.0 or 5.0).

● Access to technology is limited, similar to access to funds, especially for small players and MSMEs.

● Collaborating among people is difficult, even though Industry 5.0 emphasizes people-technology collaboration.

● MSMEs face issues with funds, technology access, and security.

Management and Industry Perspectives

● Management prioritizes productivity and quality; they may invest in technology even if it replaces labour
● Large OEMs (operating at Rs 100-150 crores) invest in hardware/software for suppliers to ensure quality and boost profit margins, pushing vendors toward technology adoption.
● Tier I MSMEs (catering to multiple OEMs) adopt technology easily; others need awareness of benefits to sustain in supply chains.

Recommendations and Solutions

Government should provide technology to MSMEs.

● Make Industry 4.0/5.0 adoption (automation and digitization) a nationwide movement, like the COVID vaccine rollout, pushing the entire supply chain.

● Collaborative effort involving government, industry, and academia.

● MSMEs should prepare via workshops, seminars on product scaling, new product development, and R&D investment (some already do this).

● Build products for international markets; adopt technology and scale up to avoid missing opportunities (e.g., AI dominance like East India Company).

● Government should create a think tank to oversee and drive this.

● Launch a gigantic nationwide movement for awareness and change management, modelled on Swachh Bharat.}

Interview 13, Minutes of the meeting Friday, 27 Feb 2026

Person who was interviewed

Dr Aiyappan Ramamurthy

Services Director,

Siemens Digital Industries Software,

Chennai

Key Points

- **Industry 4.0** principles tailored to MSMEs and the importance of ROI calculations.
- Overview of Siemens' Digital Industries vertical and recent AI-driven acquisitions.
- Decision framework for matching technology to specific business problems.
- Insights into skill gaps, workforce development, and academia-industry collaboration models.

Siemens Digital Portfolio

- **Digital Industries Vertical** – integrates shop-floor and factory automation for discrete & process sectors.
- Key technology families

Category	Example Technologies
CAD/CAM & PLM	Product lifecycle management, design simulation
MES & SCADA	Manufacturing execution, real-time monitoring
IoT & Low-code	Connected assets, rapid application development
Automation	Robotics, autonomous production, digital twins

Interview 14, of the meeting, 20-3-2026, 11.00 PM, Online

Person who was interviewed

Mr. Ramachandran,

HFS Research,

Bangalore

General introduction about SSS

1. Authored an Industry 4.0 report [7]

2. The important inhibitors for SMEs to adopt Industry 4.0/5.0 are skills/talent shortage, higher-cost of industry 4.0 adoption, lack of incentives for Industry 4.0 adoption, lack of

awareness(need for demystification) of Industry 4.0/5.0, human-less dark factory, need for awareness creation at different level within an organization

3. More examples, and case-studies on the benefits of Industry 4.0 to SMEs need to be brought out and shared instil confidence

4. Look at organizations like UNIDO. Reach out to Parikh Daruwala of Tolido

5. I and Shankar Venugopal have written a book in Tamil about EV

6.Industry 4.0 /5.0 is not a silver bullet. It won't solve all the problems faced by industries

7. How do Edu. Institutes get industry problems so that they can work on a meaningful problem which helps industries ?

8. In order to implement IIoT by MSMEs few sensors will do

9. Govt. monitored networking seminar attended by Industry and Academia is a good idea. But organizers should ensure it is outcome oriented

10. Supply chain Resilience and timely alert about supply chain problems

11. Physical AI and Humanoid are current trends

12. EV Book in Tamil

13, Skill/talent gap is a big inhibitor for implementing technology projects in MSMEs

14.Cost of implementing technology projects is another big inhibitor for MSMEs

15.There is lack of awareness about Industry 5,0 and other technology trends. Technology needs to be demystified to MSMEs

16.ASF / Srikanth / Physical AI / CII

Interview 15, Minutes of the meeting, 31-3-2026, 12.00 PM, Online

Person who was interviewed

Mr. Karthikeyan Mounaguruswamy,

CODISSIA,

Coimbatore

The meeting began with a discussion on a larger research and industry initiative around Industry 5.0, following an MOU with IIT Madras. The team explained that Dr. Kamakoti had suggested four possible areas of study: the New Educational Policy, Industry 5.0, critical review of monetary policy, and cybersecurity. Since cybersecurity was identified as a major future theme, the group chose Industry 5.0 as the main starting point. the core research question being: How ready are MSMEs to adopt Industry 5.0? The proposed methodology was to first interview thought leaders, prepare a preliminary report, and then move into a detailed study of one selected cluster.

The discussion then moved to the present state of MSMEs. It was observed that many MSMEs cannot clearly say whether they are at Industry 3.0, 4.0, or 5.0. Most of them have adopted some level of technology, such as CNC machines, but after purchasing machinery, many units remain static for 10 to 15 years without meaningful upgradation. The understanding of Industry 5.0 was described as very limited, and even the understanding of Industry 4.0 was found to be incomplete in many firms. At the same time, it was noted that awareness of digitisation has started, especially among small and medium enterprises, though actual transformation is still slow. A major part of the conversation focused on digitalisation as the first practical step. The discussion emphasized that Industry 4.0, in common parlance, begins with digitisation: payroll systems, billing, inventory linkage, ERP systems, and online process integration. It was pointed out that even a basic Tally ERP system can be the first step toward digitalisation, because it connects inventory with billing and creates a system-driven organization rather than a human-driven one. The group also discussed newer systems such as TReDS and ONDC, and noted that companies must be able to upload and manage their data systematically if they want to participate effectively in these platforms.

One strong recommendation from the discussion was that the government should create a subsidy or support scheme for ERP and digitalisation, similar to the old ISO 9000 support model. It was explained that when the government gave a subsidy of ₹75,000

for ISO certification, it helped many MSMEs understand quality systems and adopt standards. In the same way, the group felt that a new subsidy for ERP implementation, digitalisation, and related training would create awareness and give MSMEs the confidence to invest. It was also pointed out that banks do not usually give loans specifically for ERP adoption, so direct policy support is needed. The conversation also touched on practical alternatives and cost sensitivity. For micro and small units, the cost of ERP may still feel high, even if the system is useful. That is why low-cost or monthly-payment options such as Zoho were mentioned as possible alternatives. The discussion

stressed that the objective is not just software purchase, but the larger shift toward structured, scalable, and exponential growth through

systems. A serious concern raised during the meeting was the defence sector raw-material and certification challenge. The speaker explained that in defence manufacturing and reverse engineering work, raw materials are often not freely available in India, and imports are restricted because BIS certification is required. In many cases, the government itself procures raw materials and supplies them to MSMEs for manufacturing, because individual MSMEs may not be able to navigate the certification and duty structure. This was discussed as a major barrier for defence corridor industries trying to do R&D and product replacement work.

When asked about the main inhibitors for Tamil Nadu MSMEs to adopt technology, the reply cantered on three key challenges: money, skilled manpower, and the ability to convert ideas into implementation. The point made was that even if indigenous technology is available, the biggest obstacle is not the technology itself but the ability to finance it, staff it with skilled people, and move from concept to execution.

The startup ecosystem was mentioned as one area that is beginning to improve this situation by funding even deep-tech ideas. The meeting then shifted to industry–academia collaboration. It was stated that the government always says industry and academia should work together, and that funding is often linked to proving industry connection through MOUs. However, the real issue is implementation. The discussion noted that although there are many MOUs, the real value comes only when the industry's problem statements are actually taken up by academia and students. Examples were shared of colleges wanting their students to become industry-ready and of professors gaining exposure to actual industrial problems. A major concern in this section was the gap between college time and industry exposure. A three-year student spends around 1,000 days in college but only about 25–50 days in industry; an engineering student in a four-year course spends roughly 1,450 days in college but less than 50 days in industry. The discussion concluded that this gap prevents students from understanding how industries actually function. To close this gap, the group discussed internships of at least three months, industry-linked problem solving, and stronger interaction between colleges and industries. The group then discussed a more structured

model for skill development. After the primary internship, selected students would undergo short lab rotations in specialized areas such as robotics, CAD/CAM, AI, and machine learning. The idea was to identify the top 10% of students and give them multiple exposure points so that they do not remain with only one skill, but instead become multi-skilled and industry-ready. This

was linked to the broader idea of creating Centres of Excellence for future-ready skills. Another major proposal was the creation of district-level innovation hubs and community R&D centres. The idea was to establish a nodal college in each district, equipped with shared labs and facilities, so that MSMEs, students, and innovators can work together. The discussion outlined a possible governance model with state departments, industry associations, academic heads, SME leaders, and even student representatives. The goal was to create a sustainable, locally governed innovation ecosystem with regular audits, measurable outcomes, and shared accountability. The meeting also discussed multi-skill

development in a more detailed way. Instead of training people in only one narrow area, the idea was to train them in complementary skill combinations such as CAD + machine learning + robotics, or power-train + EV + Lithium-ion battery management. The notes also described possible skill clusters, including PCB and sensors, mechanical systems, AI and data analytics, robotics integration, EV and Lithium-ion battery systems, solar energy systems, and semiconductor-related training. Each cluster would be linked to a CoE and a short training duration. The discussion finally came back to the need for a formal project roadmap and detailed project report. The plan included district-wise mapping of MSME clusters, identification of skill gaps, selection of nodal colleges, preparation of a funding and costing model, and creation of a governance board for policy oversight. The overall message of the meeting was that MSMEs need a practical pathway into Industry 5.0 through digitalisation, financial support, skill development, and stronger industry-academia collaboration.

Interview 16 Meeting Transcript

Date: 2nd April **Time:** 8:30 PM

Person who was interviewed

Dr Raghavendra Prasad
Senior Consultant,
Alumnus IIT Madras,
IIM Ahmedabad

1. Opening Context: Industry 5.0 – Beyond Technology

The discussion began with a clear positioning:

Industry 5.0 is **not about technology alone** It is about **human-centricity + sustainability (ESG) + economic viability**

Dr. Raghavendra Prasad emphasized that:

- Early adopters **will incur higher costs initially**
- Lack of scale makes adoption difficult
- Therefore, **support mechanisms are critical in early stages**

Key Insight:

"If Industry 5.0 is seen only as cost, adoption will fail. It must be positioned as value creation."

2. EARLY-STAGE LEVERAGE POINTS (Critical Focus Area)

2.1 Awareness → Biggest Immediate Opportunity

- Many MSMEs are **unaware of existing government schemes**
- Tamil Nadu already has strong schemes, but **utilization is low**

Leverage Strategy:

Create a **"Go-To Manual"** Scheme mapping

How to apply

How to combine schemes for max benefit This is **low effort, high impact**

2.2 Best Practices Playbook

No structured documentation exists for: ESG adoption

Human-centric practices

Net-zero transitions

Immediate Action:

- Build a **Best Practices Manual** include:

Proven models

Implementation steps

Cost-benefit clarity

2.3 Case Study-Driven Adoption (MOST CRITICAL LEVER)

Instead of pushing concepts like:

- AI
- Blockchain
- Digital Twins

Push **REAL CASE STUDIES**

Example Shared:

- PET bottle recycling → hoodie manufacturing

Full traceability: Who collected plastic

Water usage

Carbon footprint

Result:

- Higher price realization
- Customer willingness to pay premium

Core Insight:

"When economics is visible, adoption becomes natural."

2.4 Cost-Benefit Visibility (Non-Negotiable)

- MSMEs will NOT adopt anything framed as "cost"

Every solution must show: ROI

Efficiency gains

Revenue upside

3. HUMAN-CENTRIC + ESG APPROACH

3.1 Human-Centric Gaps (Reality Check)

- Many systems are **not inclusive**

Example: Workers unable to access basic facilities in corporate spaces

Industry 5.0 must ensure:

- Dignity of labour
- Inclusivity in systems
- Practical usability

3.2 ESG Must Start at Design Stage

- Factories are **not built energy-efficiently**
- Infrastructure itself creates long-term inefficiency

Early-stage ESG leverage:

- Energy-efficient buildings
- Waste reuse systems
- Electrification (example: solar kitchens)

3.3 Grassroot Sustainability

Focus should be on: Waste segregation at source

Reducing single-use plastics

Local circular systems

Key Insight:

"Solutions must begin at origin, not at the end of the chain."

4. STRUCTURAL ECOSYSTEM SOLUTIONS

4.1 Collective Cohorts (High Leverage Model)

Need structured groups:

Types:

- Industry-specific cohorts
- Cross-sector cohorts

Benefit:

- Cross-fertilization of ideas
- Faster innovation
- Shared learning

4.2 Community R&D Model

Problem identified:

- SMEs → Have problems but no access to experts
- Academia → Has expertise but no real problems

Solution:

Community Innovation Hubs Industry + Academia + Government

Locations Suggested:

- Coimbatore
- Chennai
- Trichy
- Krishnagiri
- Ranipet

4.3 Consortium-Based Funding Model

(Strong recommendation by Dr. Raghavendra Prasad)

- Industry contributes → "skin in the game"
- Government supports
- Academia executes

Output:

- Practical solutions
- Shared IP (with priority access to contributors)

Important Shift:

Move from “discussion-based collaboration” → “funded, milestone-driven execution”

5. SKILL GAP – REALITY

- Not just lack of skills Problem is **implementation capability**

Gap Areas:

- Customization of tech
- Deployment
- Integration into existing systems

Solution:

- **Industry-specific skill development**
- Not generic programs

6. POLICY & GOVERNMENT LEVERS

6.1 What Will NOT Work:

- Complex tax incentives (leads to misuse)

6.2 What WILL Work:

- Technology upgradation funds
- Interest subvention schemes

Easier, cleaner, more effective

6.2 Scheme Integration (Hidden Goldmine)

Many schemes already exist: Housing

Skill development

Sustainability

Strategy:

- Tag and layer schemes
- Create bundled value

Example mentioned:

- Tamil Nadu already aligning with central schemes effectively

7. CLEAR ROADMAP REQUIREMENT

Every SME must have:

Defined adoption plan Timelines Measurable outcomes

Suggested approach:

- “I will implement X by Y date”
- Track progress

8. VALUE CHAIN UPGRADE (Strategic Insight)

Discussion around **Smile Curve Concept**:

- Manufacturing → Low value
- R&D + Branding → High value

SMEs must:

- Move beyond manufacturing

Enter: Innovation

Design

IP creation

But:

- Cannot do this alone → Needs ecosystem support

9. ADDITIONAL CRITICAL AREAS IDENTIFIED

9.1 Net Zero Adoption

Needs: Simple frameworks

Affordable pathways

9.2 Packaging Crisis

- Excessive single-use plastic
- No accountability

Suggested:

- Regulation + penalties
- Sustainable alternatives

9.3 Infrastructure & Energy

- Poor building design → long-term inefficiency
- Over-dependence on cooling systems

Interview 17 Minutes of the meeting held with Mr. G. V. Manimaran

1 He started with defining the stakeholders
following 3 are stakeholders in any issue
1 policy framers central and state
2 implementing agencies It could be technology or financial enablers administrators
3 users
2 According to him the major issue faced by MSMEs are products do not sustain for 10 years Hence very difficult to reap the ROI
3 Both loan component and equity component will take minimum 10 years for getting the yield
4 Funds are available PSU Banks Private banks NBFCs and Govt subsidies are available.
5 No one product is sustainable It changes within one year electronic goods change in 6 years
6 .Because of the above ROI Equity or loan gets affected
7 Competitive products and policies another major threat
8 Today on account of globalisation instead of manufacturing only assembling takes place It was not so earlier
9 Due to this profit margin comes down
10 corrective measure is interface between the stakeholders should be there
11 Policy makers at macro level should interface with the users . They should frame policies after discussing with users or train them after making policies from Day 1.
12.cited TVs as example Dynora solidaire Uptron had set up capabilities in all front like finance marketing However Flat screens were introduced and new players came in Existing market leaders were not given an opportunity. Smart players adjust and proceed but others fail
13 Globalisation is not wrong but globalisation should have identified the products and protected
14 finance related or tax related issues are modifiable .corrective measures can be taken
15 GST reforms or financial reforms are possible but policies without users' interface cannot be altered.
16 another example how products undergo changes quickly on account of technology.
gave example from construction industry. Instead of earlier conventional method of construction now pre engineering construction takes place where steel is used for the outer shell and only in-between walls are used and this is fabricated outside and not at the construction site .
17 This gives reduction in cost to 30 percent and saves time
18 in the above example if MSMEs are not informed about the technology cement and bricks manufacturers will suffer
19 Technology improvements take place without consulting with MSME and product longevity
20 suggested that govt policies should address these problems in advance.
21 Regarding funds availability no dearth of capital
However, if the MSMEs do not repay the loan the disbursing officers become accountable and unless it is changed the banks may not implement the schemes fully .

22 Though there are schemes for priority sector lending each bank has been given financial autonomy to manage
asset liability and lend based on their cost of capital.
23 The above mentioned points are the reason for non-availability of funds for MSMES.
24 In 1969 banks were nationalised .
In 1991 they were privatized. Since there were objections instead of privatising banks private sector banks were allowed to operate which started functioning like companies .
Because financial autonomy was given lending could not be directed
25 Till 95 any interest income accrued was taken for income recognition.
However, after that interest income that could not be received within 90 days were not considered as income and not only that provisions were made .It reduced the income and also the profitability
26 if it is revised to 120 it may help the bankers and MSMEs may benefit and this is doable.
27 However products becoming obsolete on account of technology or globalisation policies etc requires careful interface of users and policy makers
28 Businesses may fail on account of obsolescence natural disaster and govt policies and during that time govt should handhold . There should be a mechanism for the same
29 Because of the consumers behaviour also there could be change in consumption and losses could arise and policies to protect and inform the producers .
Takeaway interface between the users here MSMEs and the policy makers play a key role and informed decisions will help MSMEs to change their business lines protect their assets and adopt new technology

Interview 18 . Minutes of the meeting held with Mr. Ravindra , Mr. Dinesh, MACS, Sattur, Virudhunagar & Mr. Rajieve of Original Math Factory, Sattur
on 11 AM, Friday, 10th April 2026

1. Skill shortage for machinery
2. No manuals for the machinery
3. We our self-figured out and trouble-shooted and made the machines operational
4. if R&D can be done on what alternate chemical can be used to optimise to process.
5. Can robotics picker be used keeping in mind the workforce safety
6. We recure training on machines
7. Dependence on raw material is critical
8. If a lab can be setup in which we can do R&D on alternatives to Sulphur
9. We are all fully export oriented
10. Compliance is very critical for export.
11. Sattur, Sivakasi, Virudhunagar, Kovilpatti, are well known for fire cracker , matches , printing industries

Interview 19 Minutes

Person who was interviewed
Mr. Shankar Venugopal
CTO
Mahindra & Mahindra

Key Inputs Received
1. Target Clusters for Industry 4.0 / 5.0 Adoption
Large companies are fairly mature in digital transformation, yet even they are not scaling fast enough. Two broad segments were identified for targeting:
- Large and medium companies for Industry 5.0 push
- Clusters as the vehicle for focused, deep intervention

2. Automotive — Top Priority Cluster
Automotive has always led Industry 4.0 adoption due to the highly competitive nature of the business. Key observations:
- New product development timelines have shrunk from 5 years to under 1 year
- R&D and manufacturing are globally distributed and must be continuously synchronised
- Hardware and software layers must evolve together simultaneously
- OEMs expect Tier 1 suppliers to match their capability levels
- Post-EV transition, factories become smaller, modular, and more automated — making Industry 5.0 adoption natural and cost-effective
- Recommended Phase 1 focus: automotive manufacturing; other sectors to follow in Phase 2 and 3

3. Textile Industry — High Impact Cluster (Tamil Nadu)
- Textile is a massive industry in Tamil Nadu (Tiruppur, Erode belt)
- Highly energy and resource intensive — even a 5–10% reduction in OpEx delivers significant margin improvement
- Enables competitiveness even under higher tariffs (e.g., US trade pressures)
- Recommended to run a dedicated programme targeting textile industry, possibly anchored at Tiruppur

4. Auto Components / MSME Suppliers
- Auto component companies form another important cluster
- With EV transition, ICE-specific components become redundant — tires and body are among the few common parts
- Growing need for electronics, sensors, and lightweight composite materials
- Supply chain visibility needed up to 4–5 supplier levels deep

5. EV Charging Infrastructure & Decentralised Energy
- Scaling up of decentralised EV charging stations is a significant opportunity

- A corridor between Madurai and Chennai is being developed under the National EV project
- Decentralised charging with renewable energy makes a strong use case
- Solar panel financing model noted: vendor installs panels at zero upfront cost, client buys electricity from vendor for 5 years, panels remain with client thereafter — highly attractive for MSMEs

6. Green Data Centres
- Power Usage Effectiveness (PUE) below 1.5 is the benchmark for an energy-efficient data centre
- Cooling is the largest energy consumer in data centres — CFD-based battery cooling being explored
- Managing the renewable-conventional energy mix is a major optimisation challenge
- Income tax benefits tied to energy efficiency compliance is a policy lever worth recommending

7. Agriculture — Emerging Opportunity
- Acute skilled labour shortage; sudden burst demand during harvest seasons
- Automation can enable unskilled workers to perform at skilled-worker levels
- Farm-to-table tracking: wastage currently at ~50%, major opportunity to reduce through monitoring and logistics technology
- Technology accessibility for farmers remains a key question to resolve

8. Healthcare
- Telemedicine: a specialist in Bangalore can guide a local doctor in a village in real time — remote surgery guidance is already possible
- Insurance claim adjudication: more doctors are currently employed for claims processing than for actual healthcare; AI-led automation is a large untapped opportunity that insurers are deliberately avoiding to protect margins

9. Battery Passport & Circular Economy
- EV batteries should be tracked end-to-end — material origin, reused vs. new content — via a digital passport (globally called Battery Passport; India has its own framework in draft)
- Lifecycle: Automotive battery → Secondary ESS (grid/home storage) → Recycling
- Digital twin from Day 0 of material sourcing through product life is the key enabler
- Supply chain visibility, reusability, and material circularity are the three pillars

10. Sustainability as Business Case, Not Compliance
- MSMEs must be shown that sustainability directly saves OPEX — energy, water, compressed air, steam
- M&M reduced water consumption by 50% across plants — replicating even half of those measures gives others a 25% reduction
- First step is measurement: "You can only improve what you measure" — sensor-layer energy tracking is the starting point

● Message to MSMEs: sustainability is good for your business, not just a regulatory burden

11. Carbon Credits & Government Policy Recommendation

● MSMEs adopting sustainability and Industry 5.0 practices should receive green credits translating to tangible benefits — preferential tax brackets, subsidies, or grant eligibility

● EU's Carbon Border Adjustment Mechanism (CBAM) is a real export threat — MSMEs that don't adopt sustainability standards will lose access to European markets

● Tamil Nadu noted as a leading state — cleverly channelling PM Awas Yojana (PMJ) housing scheme funds to build worker dormitories near factories, improving worker welfare and productivity

● China model referenced: large factories providing full social infrastructure (housing, food, facilities) within factory premises — a model worth adapting for Tamil Nadu's migrant workforce

12. Workforce for Industry 5.0 — Skilling & Displacement

● On one hand, there is acute shortage of skilled workforce; on the other, AI, IoT, and robotics are displacing jobs — these two forces are in direct conflict and must be addressed together

● Example: Next-generation vehicles cannot be repaired at roadside garages; technicians must be trained to swap modules and read diagnostic codes — entirely new skill sets required

● World Skills Centre model (Bhopal) highlighted: tribal youth trained in welding and joining within 12 months, winning global competitions against candidates from China, Japan, Korea — a replicable model for rapid skilling

● Key recommendation: skilling programmes must be built in partnership with global organisations (as done with Singapore partners in the Bhopal model)

13. MSME Leadership & Adoption Responsibility

● MSMEs do not have the luxury of a dedicated CIO or digital transformation hierarchy

● The right target group is the next generation — children of owners, who have done engineering and MBAs, are more receptive to new ideas and are motivated to modernise the family business

● Recommendation: pitch Industry 5.0 ideas to this younger generation; they will influence their parents

● MSME size segmentation needs to be redefined meaningfully — post-RBI revised definition, medium enterprise goes up to 500 employees; recommendations must be bucketed differently for 500, 1000, and 1500+ employee organisations

14. Productivity Benchmark & Government Push

● Rule of thumb: 1 employee = ₹1 crore turnover for medium and larger enterprises

● Goal: push this ratio from 1x to 2x or 3x through Industry 5.0 adoption

● Government should be engaged to support and incentivise this productivity leap

● Government officials are now actively reaching out to industry experts for guidance on deploying allocated funds — a positive and democratic shift from earlier bureaucratic models

15. Education System — Structural Challenges

Three deep systemic issues identified:

- Faculty obsolescence: College faculty are teaching outdated content from old notes; they are not attending industry sessions and actively resist new technology introduction as it threatens their relevance
- Student-course mismatch: ~80% of students are studying courses chosen by parents rather than genuine interest; this produces disengaged graduates who are poorly matched to industry needs
- Passion-driven innovation gap: PM Modi's observation cited — India can reach the global top 10 in innovation only when each person studies what they genuinely like and works in what they are truly passionate about. Recommendation: use existing education data (LKG onwards) to identify student aptitude patterns and guide career choices early

16. Ports & Maritime — Overlooked Sector

- Ports have two components: shore side and sea side
- Shore-side back-office automation has only recently begun, even for small players
- Significant scope for IoT, digital twin, and crane automation under the Sagarmala project
- Progress is slow due to cartels and vested interests despite numerous white papers submitted
- A college in the sector has acquired a ship for students to train on — a positive development noted

Annexure – A6 – Industry 4.0/5.0 Public domain Case Studies

Case Study 1

Industry 5.0 Case Study appeared in Times of India, 25th February, 2026

Machine learning for machines
This tyre factory's efficiency soars

Sensors, computer vision models, and artificial intelligence have combined to help CEAT Tyres' Chennai factory reduce defects, waste and energy use, and improve labour and machine efficiency. The factory today runs on algorithms

Vaitheeswaran.B@timesofindia.com

Enter the large Ceat Tyres factory located in the dusty industrial belt of Sriperumbudur on the outskirts of Chennai and you are greeted by humming machines and blinking sensor lights. The manufacturing process here involves number crunching and monitoring computer screens more than heavy lifting. Over the past few years, 70% of the shop floor roles have been converted from heavy physical labour to skill-based automated work. That has also meant a lot more participation of women.

Managing mixing complexities

Each tyre has multiple compounds and materials, and these change depending on purpose – such as driving a car on a normal day, or driving the same car in snowy conditions, or pulling a truck. Durability and flexibility vary by each use case. Debashish Roy, CEAT's chief digital transformation officer, says the mixing process is the critical first step in tyre manufacturing. Think of it as the industrial equivalent of kneading dough in a bakery. In this stage, raw ingredients such as natural and synthetic rubber, carbon black and chemicals are thrown into a massive mixer to create the base material.

The goal is to blend these ingredients until they are perfectly consistent. Traditionally, factory machines followed a strict, pre-set recipe. For example, they might be programmed to mix for three minutes. However, the machine was blind and it did not know if the rubber was perfectly mixed after 2.5 minutes or if it needed four minutes. To make things more complex, natural rubber varies by batch. It might be harder or softer depending on the season. Even the temperature of the mixer changes if it has been running all day. These parameters change how fast the rubber melts. Because the system could not adjust to these changes in real time, the factory had to often run the mixers longer than necessary. This led to wasted time and lower daily output.

Roy says they built a gradient boosting regression model (machine learning model) to optimise these variations. This system continuously monitors key parameters such as temperature and energy consumption by comparing real-time data against historical "golden" batches. Based on this comparison, intelligent adjustments are made to maintain optimal conditions and improve consistency in the mixing operation.

This has resulted in an 18% reduction in mixing cycle time, a 29% reduction in power consumption, and a 32% increase in master mixer capacity. These are crucial given the factory's scale. The company now produces 350 different types of tyres in an average week, a significant jump from just 100 six years ago.



30% WORKFORCE IS WOMEN: Automation and digitisation have made hiring of women easier. Earlier, tyre building involved manual loading of rubber compounds, handling heavy beads or steel belts and physically demanding drum operations. Automated tyre-building machines standardise each step. Ergonomic fixtures and lift-assist devices reduce load, while conveyor-based tyre movement allows women to participate in building and curing operations without heavy lifting. Around 30% of CEAT Chennai facility workforce is now women. CEAT now aims to replicate this success across its other facilities.

Predicting die dimensions

As the company expands its presence across geographies, its need to develop new tyres for different terrains and environments is growing. To develop new tyres, CEAT has to design new dies. This is the process of creating the metal template or profile cutter through which hot rubber is squeezed to create specific treads, the part that touches the road. Think of it like toothpaste, where you squeeze the paste out in a specific shape depending on the nozzle attached to it. However, designing this metal plate is difficult because rubber is elastic. As soon as it is pushed out of the metal die, it relaxes and expands in a phenomenon called die swelling. Roy says if you want a rubber strip that is 200 mm wide, you cannot cut a 200 mm hole. You need to cut a 180 mm hole because the rubber will swell by 20 mm. The exact number depends on the chemical recipe of the rubber, the temperature and the speed of the machine.

Each tyre variant has roughly 60 data points, ranging from compound viscosity to machine parameters. In the past, employees mapped these points manually on spreadsheets to predict how the rubber would behave. This non-linear calculation was often inaccurate and required up to three physical trials to get it right. This iterative process resulted in longer time to take products to market and generated compound scrappage.

To address this, the company deployed a machine learning model based on Gaussian process regression. This system predicts accurate die dimensions, and has resulted in a 37% reduction in time-to-market and a 30% reduction in wastage.

Roy has also deployed AI models and solutions for export container optimisation and machine performance management. His team has built an agentic AI solution that helps junior engineers quickly understand what is wrong when a machine breaks down. It converts unstructured breakdown resolution videos into a searchable knowledge base, and retrieves past solutions via a conversational chatbot. This has enhanced troubleshooting efficiency.

WEF Lighthouse

The initiatives have brought cultural shifts where employees are encouraged to think in data driven terms. Teams regularly attend external conferences and hackathons to learn best-in-class technologies. They evaluate if a production issue is a valid business problem and whether usable data exists before developing AI use cases. The technology at the Chennai factory has been validated by experts from IIT Madras and recognised with a Lighthouse certification from the World Economic Forum. The Lighthouse awards are given to leaders in the field of technology-driven industrial transformation.

Big productivity gains

The digital initiatives have resulted in improved yields and lower energy usage, and that in turn has reduced factory conversion costs (total expense required to transform raw materials into finished products) by 20-30%. The time from order placement to dispatch has been cut by more than half, while export turnaround times have dropped from 120 days to 55 days.

DECENTRALISED DIGITAL TEAMS

CEAT has built the tech solutions ground up with internal teams, and is thanks to digitisation efforts that began in 2021, involving the installation of sensors, manufacturing execution systems and dashboards. The company now invests 10% of its manufacturing capital expenditure on digital transformation initiatives. To bridge the gap between technical teams and shop-floor reality, it introduced a new role called business translators. These are folks with strong technical skills and work directly with shop floor operators to identify pain points. **Debashish Roy**, chief digital transformation officer, says it's a decentralised digital team. Centralised teams, he says, may take years to learn a process.



Figure 23: Machine learning for machines in tyre factory

Case Study 2

Engineering asset management (EAM) group, department of mechanical engineering, IIT-M.IIT Madras develops AI framework for real time gearbox fault detection TNN | Aug 31, 2025, 12.10 AM IST,

Chennai: Indian Institute of Technology Madras (IIT-M) researchers have developed a new artificial intelligence (AI) framework to detect faults in gearboxes used in cars and other vehicles, pumps, and heavy industrial machines. The system works in real time even with vibration sensors used to detect faults in a gearbox placed in non-ideal locations, avoiding the need for costly design changes.

The IIT-M team created a method that uses reinforcement learning (RL), a branch of AI where a computer program learns through trial and error. In factories, engineers normally use vibration sensors to monitor gearboxes. However, placing these sensors in the right locations is often difficult because of heat, wiring, space limits, or exposure to fluids, making fault detection unreliable.

The IIT-M framework solves this by using a ‘multi-sensor fusion approach'. Data from several sensors, even when placed in non-ideal positions, is combined and filtered using an ‘adaptive filtering technique'. This helps isolate fault signals from background noise. The RL agent then selects the best parameters for accurate analysis.

"In the lab, things are simpler as the person performing experiments usually knows where the fault is and can place sensors immediately next to it. However, in real industrial settings, the field engineers do not always know precisely where the issue is, and if they do, placing sensors close enough is not always possible. That is where the proposed framework comes in," said Shahis Hashim, researcher at engineering asset management (EAM) group, department of mechanical engineering, IIT-M. "While it is currently tested on gearboxes, the proposed approach can be applied across many industrial systems," said EAM group researcher Sitesh Kumar Mishra.

The method was tested on a gearbox in the laboratory and was able to assess faults quickly and reliably. A gearbox controls the speed and torque of machines by transferring power from one component to another, making it essential in vehicles and industrial equipment. Monitoring gearboxes helps detect faults early, preventing breakdowns, costly repairs, and safety risks. "Our algorithm fuses data from non-ideal sensor locations, enhancing fault detection—an urgent need we address," said professor Piyush Shakya, who leads the EAM group at IIT-M

Case Study 3

V.O. Chidambaranar Port becomes First Indian Major Port to Implement Digital Twin the V.O. Chidambaranar Port Authority has achieved a major technological milestone by becoming the first port in India to launch the Digital Twin initiative for port management. The Port has marked a significant step toward smart, efficient, and technology-driven maritime management. The platform was inaugurated on 23.02.2026 by Sarbananda Sonowal, Hon'ble Union Minister of the Ministry of Ports, Shipping and Waterways, marking a significant milestone in the Port's journey toward intelligent and technology-driven maritime management.

The Digital Twin platform will create a real-time virtual replica of the port's infrastructure, operational assets, and maritime ecosystem, enabling enhanced operational visibility, predictive analytics, and data-driven decision-making across the port. By integrating advanced technologies such as IoT sensors, GPS tracking, LiDAR mapping, drone imaging, and CCTV networks, the platform will continuously mirror real-time conditions, enabling efficient coordination among all operational departments. The Digital Twin Platform enables real-time operational monitoring, providing live visualisation of berth occupancy, vessel movements, crane utilisation, and yard capacity across the port. It supports predictive maintenance of cargo handling equipment through AI-based asset monitoring, helping to minimise equipment downtime and improve operational reliability.

The system facilitates berth and traffic optimisation by enabling intelligent scheduling of vessels and cargo operations, thereby reducing congestion and waiting time. In addition, the platform shall also provide energy and emissions tracking to support data-driven sustainability management and include scenario simulation capabilities that allow operators to conduct "what-if" modelling to prepare for peak demand situations and operational disruptions.

The platform is designed to support the Port's transformation into a smart and efficient maritime gateway by reducing vessel turnaround time by up to 25%, improving equipment availability and reliability, enhancing operational safety through predictive alerts, and optimising energy utilisation to lower carbon emissions. The project is being implemented in a phased and planned manner. The full-fledged Digital Twin initiative is expected to strengthen resilience against potential operational disruptions while enabling more efficient, sustainable, and data-driven port operations.

Under Maritime India Vision 2030 and Amrit Kaal Vision 2047, Shri Narendra Modi, Hon'ble Prime Minister of India, has envisioned the importance of digitalisation and technological advancement in the maritime sector to improve efficiency, transparency, and the global competitiveness of Indian ports. As part of MIV Vision 2030, globally benchmarked targets have been defined to enhance EoDB and achieve high operational efficiency through technology. V.O.C Port is all set to achieve this national vision and continue to move forward toward achieving international port standards through the adoption of advanced digital and smart port technologies.

Case Study 4:

Using model-based systems engineering to take a new approach to virtual NVH development

Hyundai Motor Group uses Simcenter to combine simulation and test to build a digital twin

https://resources.sw.siemens.com/hu-HU/case-study-hyundai-motor-group/?utm_source=chatgpt.com

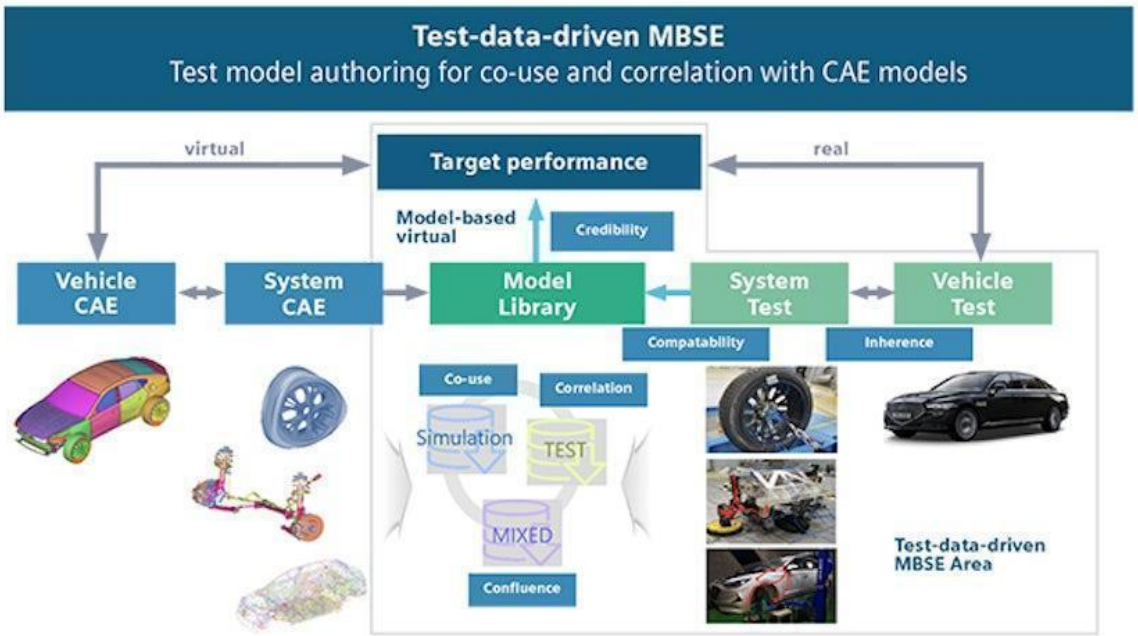


Figure 24: HMG's test-data-driven MBSE for authoring test models for virtual development

Case Study 5

Tesla Case Study

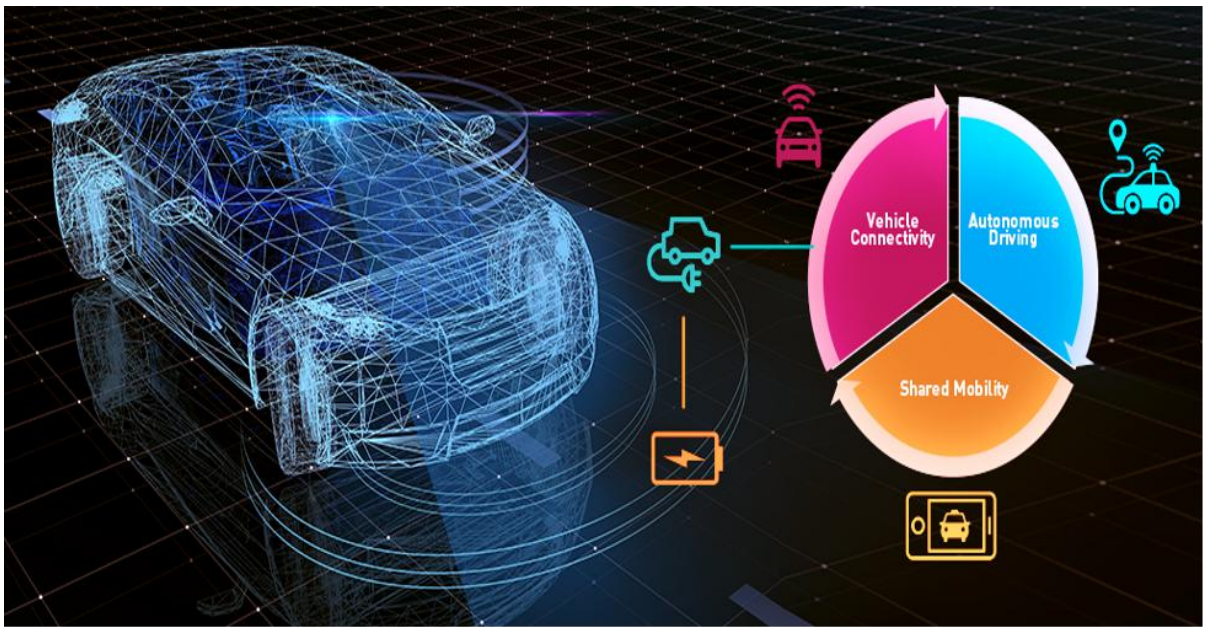


Figure 25:http://bit.ly/4tzcMGM

Case Study 6

BMW case Study



Figure 26: https://www.bmwgroup.com/en/news/general/2023/aiqx.html

Case Study 7

IIT Madras develops and deploys new technology to treat Wastewater from Textile Industry[41]



Figure 27 : Reactor installed at CETP, Tiruppur

Following Case Studies 8, 9, 10 Shared by Mr. Venkatesan

Case Study 8

Auto Component MSME (Pune Cluster)

Problem

- Rejection rate: 8–10%
- Manual inspection → inconsistent quality
- OEM pressure (Tier-1 supply requirement)
- Implementation (Actual Shopfloor Execution)

Step 1: ***Machine Data Capture (IoT Layer)***

- Installed current sensors + cycle counters on CNC machines
- Connected via Modbus → IoT gateway → local server

Step 2: *AI Vision Quality System*

- Installed industrial cameras at inspection station
- Trained AI model on:
- Good parts
- Defect samples (scratches, burrs, dimension issues)

System:

- Camera → Edge PC → AI inference → PASS/FAIL signal
- Integrated with stack light + rejection chute

Step 3: ***MES Integration***

Basic MES layer created:

- Production count
- Rejection tracking
- Operator login

Step 4: Human Integration (Industry 5.0 element)

- Operator does:
- Final validation override
- AI correction tagging (continuous learning)

Financing Model

- Used M1xchange (TReDS)
- Discounted OEM invoices
- Released working capital in ~3–5 days
- Capex funded from improved cash flow (no term loan)

Outcome

- Rejection ↓ 10% → 2.8%
- Inspection manpower ↓ 40% (redeployed, not removed)
- ROI: ~14 months

Case Study 9

Precision Engineering MSME (Coimbatore)

Problem

- Frequent spindle failures
- Unplanned downtime → delivery delays

Implementation

Step 1: *Sensor Deployment*

Installed:

- Vibration sensors
- Temperature sensors
- Mounted on spindle housing

Step 2: *Data Pipeline*

- Sensor → PLC → Edge gateway
- Data stored in:
- Local server / cloud (InfluxDB-type setup similar to your architecture)

Step 3: *Predictive Model*

Baseline created:

- Normal vibration signature

ML model trained to detect:

- Bearing wear
- Misalignment

Step 4: *Alert System*

Threshold + AI hybrid:

- SMS / dashboard alerts
- Maintenance scheduling

Step 5: *Human-Machine Collaboration*

- Maintenance team validates AI alerts
- Feedback loop improves model accuracy

Financing Model

- Equipment leasing model
- Sensors + system provided by vendor
- Paid as monthly Opex (₹40–60k/month)
- No upfront burden → easy adoption

Outcome

- Downtime ↓ 35%
- Maintenance cost ↓ 20%
- Delivery reliability improved → OEM rating increased

Case Study 10

Textile MSME (Tiruppur Cluster)

Problem

- High electricity cost (15–18% of production cost)
- No visibility on energy consumption

Implementation

Step 1: Smart Metering

Installed energy meters on each major load:

Dyeing machines

Compressors

Boilers

Step 2: Data System

Energy meter → IoT gateway → cloud dashboard

Step 3: Analytics Layer

Identified:

Peak load times

Idle running machines

Inefficient compressors

Step 4: Control Actions

Shifted loads to: Off-peak tariff periods

Installed: VFD on compressors

Automated shutdown of idle machines

Step 5: Human Integration

Supervisors trained to:

Monitor dashboard

Take daily energy decisions

Financing Model

Used SIDBI + state subsidy scheme: ~30% subsidy on energy efficiency projects

Outcome

- Energy cost ↓ 22%
- Payback: ~12 months
- Sustainability compliance improved (export benefit)

Important Lessons Learnt from These Case study

Real Industry 5.0 Pattern (India MSME Reality)

1. Start Small (Not full automation): One machine / one line / one problem
2. Build Data First: Sensors → visibility → insight
3. Add AI Later: Only after data is stable
4. Keep Humans in Loop: Operators validate → system improves

1. Use Smart Financing
2. TReDS → working capital
3. Leasing → avoid capex

Annexure – A7

Sample Industrial Problems Requiring Solutions

1).Sintering-process optimization that focuses on **real-time monitoring of belt speed and load distribution** is about using **online sensors and data-driven control** to keep bed depth, temperature profile, and permeability within tight bounds.sciencedirect+2

Why belt speed and load distribution matter

- **Belt speed** directly controls **sintering time**, flame front velocity, and heat-balance; too fast reduces productivity and quality, too slow wastes energy and capacity.jstage.jst+1
- **Load distribution** (i.e., bed thickness and particle segregation across the width) affects **air permeability**, ignition uniformity, and final sinter strength and size distribution.tandfonline+1

Typical real-time monitoring strategies

- **Belt-speed sensing:** Encoders or tachometers on the sinter machine drive, feeding into the plant DCS or an ML-based optimizer to adjust speed relative to feed rate and flame-front position.tecnologiammm+1
- **Load-distribution sensing:**
    - Laser or 3D-lidar systems scanning the bed profile to detect **uneven layering and segregation**.keenviewtechnology+1
    - Weight-belt or load-cell arrays across the feed-end to estimate **mass per unit length** and detect over-/under-loading.keenviewtechnology+1
- **Performance-based feedback:**
    - Automated models (e.g., machine-learning or DEM-based) that correlate belt speed, layer height, and segregation with **sinter productivity, strength, and size distribution**, then recommend set-point adjustments.sciencedirect+2

Annexure – A8

Description, References and Institutes involved in Industry 5.0 solutions mentioned in Section 11

29.1 Smart machining integrates CNC machines with **IIoT sensors, data analytics, and AI** to monitor machining conditions (tool wear, vibration, temperature, energy) in real time and enable predictive maintenance, adaptive control, and improved quality.

Book Reference:

Smart Machining Systems: Modelling, Monitoring and Informatics (Book), Springer
Advanced Manufacturing Technology Development Centre (AMTDC)

T.N Edu: Smart Manufacturing & Digital Transformation Centre (SMDTC) , IIT M

G.L Samuael

29.2 CNC automation and in-line metrology
CNC automation with **in-line metrology** integrates measurement systems (probes, vision, laser scanners, CMMs) directly into machining processes to enable **real-time inspection, error compensation, and zero-defect manufacturing** without removing the part from the machine.

Ref: IIoT-based condition monitoring of machining processes (2023)

Advanced Manufacturing Technology Development Centre (AMTDC), IIT M

T.N Edu: Anna University, PSG Tech → metrology + manufacturing

29.3 Digital twin for material–performance optimization
A **digital twin** is a virtual replica of a material, component, or process that uses real-time data and physics-based models to **simulate, predict, and optimize material behaviour (strength, fatigue, thermal response) and overall performance during manufacturing and service life**.

Digital Twins for Materials (Frontiers in Materials, 2022)

T.N Edu Smart Manufacturing & Automation Lab, IIT T, Anna University

29.4 AI-based predictive quality for heat treatment
AI-based predictive quality in heat treatment uses **machine learning models (ANN, CNN, ensemble methods)** with process data (temperature, cooling rate, time, composition) to **predict material properties (hardness, toughness, microstructure) and ensure consistent quality without trial-and-error experiments**.

"AI-based optimisation of machining performance: A review" (CIRP, 2024), **Edu:**AMTDC,IITM

Advanced Manufacturing Technology Development Centre (AMTDC), IIT M

27.9 Vision-guided robotic assembly
A robotic assembly approach where computer vision systems (cameras + image processing) provide real-time feedback to guide robots in detecting, localizing, and assembling components with high precision and adaptability.

Singh et al., *"A Survey on Vision Guided Robotic Systems with Intelligent Control Strategies for Autonomous Tasks"* (2022) – comprehensive overview of vision-based planning and control in robotic systems

Image Guided Robotic Systems (IGRS), HTIC, IITM

Robotics Lab + Industrial Automation Lab, NIT Trichy

Vision Systems Lab, TCE Madurai

27.10 SMT automation with AI-based optical inspection

SMT automation with AI-based optical inspection combines surface-mount production equipment with machine-vision and AI models that inspect PCB assemblies for missing parts, polarity errors, solder defects, and placement issues in real time. human-centric, adaptive quality system that supports operators with better defect classification and faster intervention.

white paper, "*Unlocking AI for Automated Optical Inspection*" released today by IPC's Chief Technologist Council, focuses on AI's role in AOI processes for printed circuit board assemblies (PCBAs).

https://smttoday.com/2025/02/11/new-ipc-white-paper-focuses-on-use-of-artificial-intelligence-in-automated-optical-inspection-in-electronics-manufacturing/

IIT M

The 'Veena and Pratap Subrahmanyam Centre for Digital Intelligence, Security Hardware and Architecture' (V&PS – CDISHA)

27.11

Monitor and optimize the application of thermal interface materials (TIMs) and the validation of sealed components in manufacturing. Industry 5.0 human-centric workflows through predictive analytics and real-time feedback. The topic spans jet dispensing of liquid metals, thermal imaging leak detection, and machine learning for predictive quality in EV battery and other critical systems.

Kalasalingam University in Krishnankovil, Tamil Nadu, is explicitly cited in a paper on vacuum leak detection using infrared thermal imaging for piping, making it directly relevant to the leak testing analytics portion of this topic.[cite:42]

27.12

High-voltage wiring harnesses, digital work instructions, and end-to-end traceability are central to Industry 5.0 for electric vehicles, industrial power systems, and aerospace manufacturing. .Digital work instructions on tablets or AR devices guide operators step-by-step, while barcoding/RFID and MES systems enable full traceability from raw materials to final assembly

IIT Madras :

high-voltage engineering and power-electronics program

wiring-harness certification course with TNSDC.

27.13

Digital twin-based charger testing. Creates a digital twin of the charger and its grid interface to simulate AC/DC charging cycles, fault scenarios, and communication stacks before physical EOL testing, reducing prototype-to-production time. The twin can be reused for predictive maintenance and software updates in the field

"A Comprehensive Review on Charger Technologies, Types, and Standards," 2024, V.N. Saraswathi, Vijaya Priya Ramachandran , VIT, Vellore, India

Indian Institute of Technology (IIT) Madras hosts an 'EV Charging Technology Laboratory' and an 'Vehicle Engineering Laboratory' that provide hands-on training and research on power-electronics, EV charging systems, and battery-related testing

27.14 Smart Factory SMT Line with AOI & MES Integration(27.14)
An Industry 4.0 SMT line integrates surface-mount technology machines with AOI (Automated Optical Inspection) and SPI (Solder Paste Inspection), feeding real-time quality and process data into a Manufacturing Execution System (MES) for closed-loop process control and predictive defect reduction.

Article: "Solving the Integration Puzzle in SMT Manufacturing" (Athena Tech, 2025) – discusses AOI and SPI integration with MES using IPC-CFX-style data exchange.

Anna University – Centre of Excellence in Industrial Automation (Chennai

Sri Vijay Vidyalaya College of Engineering (Sriperumbudur region): Electronics / Instrumentation groups work with nearby SMT-line tenants in SIPCOT for MES-linked data-collection prototypes

27.15

Automated calibration of MEMS sensors using robotic or test-rig platforms, combined with data-driven analytics (e.g., regression, ML, statistical process control), to improve measurement accuracy, drift compensation, and suitability for industrial or IoT-smart-factory environments.

https://www.automate.org/news/digital-twins-and-the-future-of-smart-manufacturing

Anna University Chennai – Centre for Internet of Things (IoT) + Centre for Robotics and Automation

IoT CoE works on sensor-network calibration, data-quality issues, and IIoT analytics;

27.16

Collaborative robots (cobots) integrated into winding and assembly lines, with embedded sensors and data-driven analytics for real-time process monitoring and predictive maintenance to reduce unplanned downtimes and ensure quality-driven production.

PSG College of Technology, Coimbatore**,** Department of Robotics and Automation Engineering + Centre for Advanced CNC and Robotics: Uses UR5 collaborative robots in labs and robot-loaded CNC/VMC cells, and explicitly trains on Industry-Robot Programming & Operations framed in an Industry 4.0 / smart-factory context

27.17 F**lexible automation with poka-yoke and traceability**
Flexible automation systems (e.g., reconfigurable workstations and modular cells) integrated with poka-yoke (error-proofing) mechanisms and end-to-end traceability (via barcodes, RFID, or IIoT tags) to ensure zero-defect, quality-oriented, and trackable production in dynamic, low-volume-high-mix environments. “Poka-Yoke Meets Deep Learning: A Proof of Concept for an Assembly Line Application”

https://www.mdpi.com/2076-3417/12/21/11071

PSG Tech, Coimbatore – Centre for Robotics & Automation + CNC/Robot cells

IIITDM Kancheepuram – Smart Manufacturing Lab (IoT + Digital Twin labs)

27.18

Automotive LED-lighting assembly lines using machine vision systems for precise optical alignment of LED modules and automated photometric testing rigs (e.g., integrating goniometers, spectroradiometers, or camera-based luminance sensors) to ensure compliance with standards, uniformity, and production-rate-bound quality control

“Machine Vision System for Automatic Adjustment of Optical Components in LED Modules for Automotive Lighting” Link: https://www.mdpi.com/1424-8220/23/21/8988

IIITDM Kancheepuram – Smart Manufacturing Lab

27.19

Smart gear machining with condition monitoring refers to the integration of sensors, AI/ML, and IoT into gear manufacturing processes (e.g., hobbling, milling) to **monitor tool wear, vibration, and process conditions in real time**, enabling predictive maintenance and improved machining quality.

“Research progress on intelligent monitoring of machining condition” (2025) Covers sensor fusion, signal processing, and intelligent diagnostics.

Advanced Engineering Informatics Volume 67, September 2025, 103518**, Review article, Research progress on intelligent monitoring of machining condition based on indirect method,** Ma Yaoguo , Yao Changfeng , etc. al

29.20

Precision casting and connected foundry systems involve **high-accuracy casting processes integrated with digital simulation, IoT, and data analytics** to predict defects, optimize mould design, and enable smart, interconnected foundry operations

Casting Simulation & Digital Foundry (India – IIT work) *Auto CAST simulation software details*

Modern foundries combine:

- Simulation (Auto CAST, PoligonCast)
- Sensor-based monitoring
- Digital process optimization

AutoCAST Developed at IIT Bombay; enables **mould filling & solidification simulation, defect prediction, and casting optimization**.
https://en.wikipedia.org/wiki/AutoCAST?utm_source=chatgpt.com

1. **PSG College of Technology**
2. **Coimbatore Institute of Technology**

- Works on:
    - **Manufacturing automation, casting processes, and industrial IoT**
    - Strong linkage with **precision casting industries in Coimbatore cluster**

29.21

Robotic balancing and torque traceability involve **designing robots with force/torque-balanced mechanisms and ensuring accurate, traceable measurement of torque through calibrated sensors**, enabling stable motion control, precision tasks, and reliable quality assurance in robotic systems.

- Balancing reduces actuator effort and improves stability.
- Torque traceability ensures **measurement accuracy linked to standards (calibration chain)** for industrial and robotic applications.

A Review of Mechanical Design Approaches for Balanced Robotic Manipulation , Yash J. Vyas, Volkert van der Wijk and Silvio Cocuzza, *Robotics* 2025, *14*(11), 151; https://doi.org/10.3390/robotics14110151

IIT Madras, NIT Trichy, Anna University, and VIT

29.22

Forging analytics and digital process control involve the use of sensor data, AI/ML, simulation, and real-time monitoring systems to analyse forging parameters (force, temperature, deformation) and enable adaptive control for improved quality, defect reduction, and productivity.

Journal of Manufacturing Processes Volume 121, 15 July 2024, Pages 193-204, DeepForge: Leveraging AI for microstructural control in metal forming via model predictive control, Jan Petrik, Markus Bambach

Manufacturing Engineering Lab, **Indian Institute of Technology Madras**

29.23

Automated test rigs with real-time data capture are **computer-controlled experimental systems integrated with sensors and data acquisition (DAQ) units** that continuously monitor parameters (force, vibration, temperature, etc.) and provide **instant feedback, analysis, and control during testing**.

Bharath, T.S. et. al. Design and Development of Automated & Programmable Testing Rig for Sensor Characterization, International Journal of Engineering Research & Technology (IJERT.ORG)

IIT/NIT/ IIITB/major Engineering Institutes in Tamil Nadu

29.36

AI-driven defect detection for trim quality and NVH (Noise, Vibration, Harshness) reduction involves using computer vision and acoustic AI models to automatically identify surface defects (scratches, gaps, misalignment) and abnormal noise/vibration patterns, enabling **zero-defect manufacturing** and improved vehicle comfort**.**

All major OEMs are converging towards a common model: AI + Digital Twin + Real-time Data = Smart Manufacturing + NVH Optimization

Artificial Intelligence for Quality Defects in the Automotive Industry: A Systemic Review, Oswaldo Morales Matamoros et al., *Sensors* 2025, *25*(5), 1288; **https://doi.org/10.3390/s25051288,** (This article belongs to the Special Issue Leveraging Advanced AI for Smart and Sustainable Industry 4.0 Solutions)

29.37

Smart assembly lines and thermal performance analytics involve the use of AI, IoT sensors, and digital twins to optimize assembly operations, while simultaneously monitoring and analysing thermal behaviour (heat generation, cooling efficiency) of systems in real time to improve energy efficiency, reliability, and sustainability.

Advancing Sustainable Smart Manufacturing: A Comprehensive Review of Machine Learning Techniques in Assembly Lines**,** Hassan Hijry, Department of Industrial Engineering, University of Tabuk, Tabuk 47512, Saudi Arabia *Sustainability* **2026**, *18*(1), 348; https://doi.org/10.3390/su18010348

(This article belongs to the Special Issue Innovative Strategies for Net-Zero Carbon Cities Integrating Renewable Energy, Smart Infrastructure and Circular Economy Models)

VIT Vellore, PSG Tech, IIT M - Smart factories, IoT-enabled assembly lines

29.38

A digital twin for thermal-flow optimization creates a real-time virtual model of thermal systems (heat transfer, fluid flow, cooling systems) to simulate, predict, and optimize energy efficiency, temperature distribution, and flow dynamics in manufacturing processes.

Digital Twins Case study [34]

https://bit.ly/4cnW3k8

Thermal Engineering Lab, Robert Bosch Centre for Data Science & AI,IIT Madras

28.39

IoT-enabled motor testing integrates sensors (current, voltage, vibration, temperature) with cloud/edge analytics to monitor motor performance in real time, enabling efficiency analysis, fault detection, and predictive maintenance in industrial systems

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"IoT-based health monitoring and fault detection of industrial AC induction motor for efficient predictive maintenance"

Muhammad Yousuf et al
Volume 57, Issue 8
https://doi.org/10.1177/00202940241231473
IEEE Transactions on Automate... >Volume: 16 Issue: 1

A Survey of Automated Threaded Fastening Zhenzhong Jia and others Electrical Machines Lab, Robert Bosch Centre for Data Science & AI, IIT Madras

28.40 Automated fastening systems use **robotic or powered screwdrivers integrated with torque sensors and data acquisition systems** to perform tightening operations while capturing **torque–angle/torque–time signatures** for quality control, traceability, and defect detection in assembly lines.

These systems ensure **correct tightening, joint integrity, and zero-defect manufacturing**.

https://ieeexplore.ieee.org/document/8392410

14.1

This topic integrates automated fabric cutting (CNC/laser), robotic/AI-based sewing systems, and Manufacturing Execution Systems (MES) to enable a digitally connected garment production line with real-time monitoring, improved precision, reduced waste, and end-to-end production control.

Industry Insight (IIT Madras – Textile Automation Context)

- Article: “AI Stitch in Time” (IIT Madras Shaastra Magazine, 2024)
- Key Insight:
    - Robots are being developed for fabric handling, sewing, inspection, and folding, showing the transition toward fully automated garment production

Anna University, Textile Technology

14.3

Wearable health monitoring systems have gained considerable interest in recent years owing to their tremendous promise for personal portable health watching and remote medical practices. The sensors with excellent flexibility and stretchability are crucial components that can provide health monitoring systems with the capability of continuously tracking physiological signals of human body without conspicuous uncomfortableness and invasiveness.

Flexible, stretchable sensors for wearable health monitoring: sensing mechanisms, materials, fabrication strategies and features

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Y Liu, H Wang, W Zhao, M Zhang, H Qin, Y Xie
Sensors, 2018•mdpi.com

14.11

To mitigate the environmental impacts, textile industries in India are mandated to implement **ZLD systems**, which aim to recover and reuse wastewater and salts. However, the conventional ZLD process is associated with high capital and operating costs, significant energy consumption, and a large carbon and area footprint.

Prof. Indumathi M. Nambi of IIT Madras, this pilot project was implemented at Kunnakalpalayam Common Effluent Treatment Plant (CETP) in Tirupur district of Tamil Nadu during 2023.

The active participation of researchers from IIT Madras, Germany, and industry scientists greatly contributed to the workshop's success. The in-person consortium meeting on November 30th, 2023, brought together researchers from IIT Madras, Goethe University, RWTH from Germany, and industry partners Eurofins and Tamilnadu Water Investment Company (TWIC) to discuss the project's progress, challenges, and future directions. This collaboration has fostered innovation and knowledge exchange, leading to the successful inauguration of the pilot plant.

https://www.iitm.ac.in/happenings/press-releases-and-coverages/iit-madras-develops-and-deploys-new-technology-treat

Appendix A9:

Quarterly MSME-cluster-Academia-workshop Agenda

Time	Topic	Presenter

Venue : Cluster MSME association Hall

Welcome by MSME association President

10.00 AM : Current problem faced by Industry: MSME representative

10.30 AM : Latest Trends in Industry 5.0 an Industrial Research : Faculty from Engineering Institute

11.00 AM : Paper presentation by Faculty

11.00 AM : Technology Demo by Institute or MSME

12.30 PM : Q & A

Summary & Concluding Remarks

Vote of Thanks

Appendix A10: India AI Mission

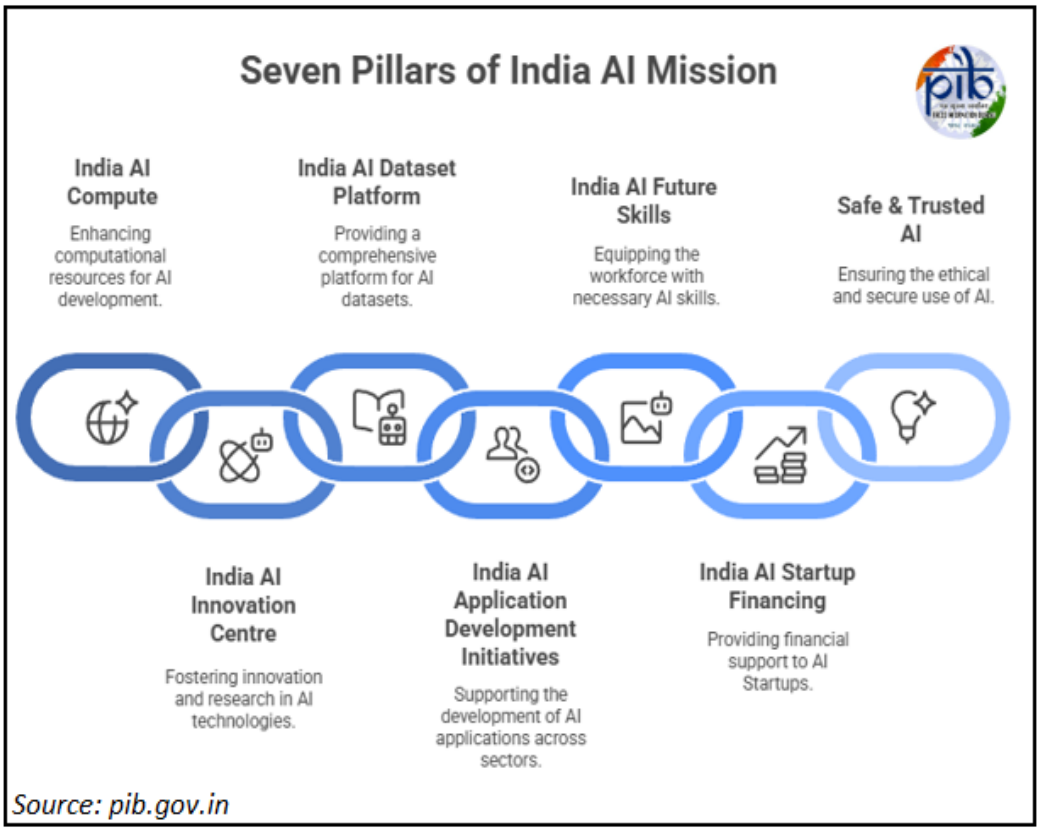


Figure 28: India AI mission

Appendix A11: Additional Notes on Recommendations

1. **Community R&D**

   Tamil Nadu Govt. should setup SME cluster specific community R&D centers in important clusters namely Sriperumbudur, Tiruvallur, Coimbatore, Hosur and Ranipet. It will be a game changer for TN MSMEs. community R&D be a cost saving innovative initiative by TN Govt. to support the cash starved MSMEs of Tamil Nadu? Community R & D is increasingly seen as a strategic necessity for the Tamil Nadu government to support its nearly 5 million MSMEs. By shifting from an "individual firm" model to a "community-shared" model, the government can transform R&D from a luxury that cash-starved units cannot afford into a shared public utility.

   R&D facility should focus on key MSME clusters:

   Short Term(6-8 months): Study how existing private company operated community R&D efforts

   Mid Term(8-18 months):D

   Long Term(beyond 18 months):

   Existing Community R&D models to learn from:

   1. TCS & Wipro
   2. China model

   Any reference documentation:

   Reasoning – Why?

   For a typical MSME in clusters like Coimbatore (Pump sets), Tiruppur (Textiles), or Hosur (Auto components), the cost of setting up an independent lab is prohibitive. Community R&D solves this through Collective Intelligence and Shared Infrastructure.

   Investment Required: Model can be 50% public and 50% MSME association

   Caution: care should be taken in such a way that this R7D only serves only certain group interest

   Business case – Justification

2. **Upskilling program** - **What?**

   - Partner with Skill India, other institutions and engineering institutes mentioned in [Centre of Excellence, Research Centres in TN] for training in digital tools, focusing on operational staff.

   - Aggressively impart vocational and suitable Industry 4.0/5.0 technology training.
   - As part of the upskilling, introduce completed solution case studies using Industry 4.0/5.0

   Reasoning – Why? For a typical MSME

   Business case - Justification

3. **Low-cost Tools** - **What?**

   Start with low-cost tools like cloud computing and IoT sensors for machine monitoring, progressing to AI

   Reasoning – Why?

   A textile MSME in TN used IoT for real time tracking of textile machinery performance. Reduced downtime by 30%.

Business case – Justification

1. **Collaboration**
2. **Carry out Skill Census**
   Skill Census exercise can comprehensively assess current skill levels across the state's regions and sectors. All states can undertake this activity. This will help map out the exact skills that are deficient and in line with industry demands at a granular level.
3. **Get Product Quality Certified**
   Product Quality Certification. The main objective of this scheme is to encourage MSMEs to Acquire Product Certification Licenses from National / International Bodies, thereby improving their competitiveness. The primary objective of this activity is to provide subsidy to MSME units towards the expenditure incurred by them for obtaining product certification licenses from National / International standardization Bodies. Under this Activity, MSME manufacturing units will be provided subsidy to the extent of 75% of the actual expenditure, towards licensing of product to National/International Standards. The maximum GOI assistance allowed per MSME is Rs.1.5 lakh for obtaining product licensing /Marking to National Standards and Rs. 2.0 lakh for obtaining product licensing /Marking to International standards. One MSME unit can apply only once under the scheme period.
4. **Upgrade outdated technologies**
   upgrading outdated technologies and improving marketing and branding capabilities are critical to improving competitiveness.
5. **Help MSMEs to cope up with bureaucratic issues, compliance issues**
6. **Support every TN MSME to prepare a growth strategy roadmap based on Industry 5.0**
7. **For every member of a Leader-group, identify and associate an advanced Academic Research Institute**
8. **Publish completed Industry 4.0/5.0 Case studies and make it available to all the SMEs and academia. This will instil confidence amongst the SMEs on the power, effectiveness of Industry 5.0 and the need for adopting the same in their industries.**
9. **Incentivize SMEs who attain their sustainability goals. Incentives should be subsidized upgrade of their older systems and machineries**
10. **Quarterly Industry 5.0 networking events in each cluster participated by SMEs, other industries and academic institutions in that cluster**

Appendix 12: Layered Strategic recommendations for Cybersecure-MSMEs

This appendix is provided by Vittal Raj

While digital transformation based on Industry 4.0/5.0 are increasingly a critical success factor for MSME Growth in a burgeoning Digital Economy, however they also come with inherent cyber risks of cyber-attacks and digital frauds. Hence it is imperative for MSMEs to manage their cybersecurity risks, commensurate with their nature and size of business and technology dependence.

These recommendations are based on the following Pillars:

1. **Transforming Cybersecurity Behavioural Change**
2. **Minimum Control Adoption across MSMEs**
3. **Ecosystem & Vendor Risk Governance**
4. **Incident Response & Recovery Readiness for common cyberattacks and Digital Frauds**

In context, the following recommendations may be considered for upgrading awareness and adoption of cybersecurity hygiene amongst MSMEs:

B. Ushering in Behavioural Change in MSMEs towards cybersecurity

a. Creating mass awareness campaigns with local language support based on MSME size and technology dependence/maturity (layered approach) based on philosophy of Behavioural Change rather than mere one time trainings. These could be continual programs with repeated messaging using multi-modal out-reach approach.

b. Use-Case based Trainings (themed common attacks e.g. Payment frauds, E-mail frauds ransomware attacks, deepfake scams, employee digital frauds, IT vendor frauds etc.) targeting Cybersecurity Trainings for MSME boards/governing body/owners and functional leaders with suitable outreach strategies

c. Such campaigns are not merely Dos & Donts but based on real life scenarios and use cases that highlight the gravity of ignoring Cybersecurity Risks and their devastating impact on MSME business.

d. Work with Local and Central government to provide policy recommendations for intense outreach programs such as working with MeiTy (Cyber Surakshit Bharat Initiative), DSCI, Digital MSME Scheme, APAC MSME Cybersecurity Fund.

e. Provide knowledge leadership in designing such programs and ToT. The content for such campaigns will include a combination of micro learning, real-incident gamification simulations that MSME can apply to themselves and self-assessments.

C. **MSME Sector Specific Cybersecurity Baseline Frameworks:** Identifying Key focus areas for MSMEs based on Business Impact Cybersecurity Assessments, Identity security (MFA), Backup & recovery, Payment fraud controls, Vendor risk management, Incident response readiness

   a. Work with agencies such as TN (TN Cybersecurity Policy, TIDCO and ELCOT) and MeiTy,CERT-IN, MHA,DSCI to create the baseline Framework for minimal MSME Cyberseucrity that can be comfortably adopted by any MSME supporting sector specific Industry 4.0/5.0 (AI, IoT, SCADA, Robotics etc.) requirements.

   b. **Certified Cybersecure MSME Units** : Work with Government to issue guidelines for Greater Recognition of Certified Cyber-Secure MSME Units in Procurement/allotment of orders e.g. GEM Portal etc. for Certified Cybersecure MSME Units.

      i. Work with Government to give greater recognition/score to MSMEs that are certified for Good Cybersecurity based on Audits.

      ii. Work with Government to issue directions mandating Cybersecurity certification as a pre-condition to PLI and other Incentives, major procurement orders and tenders, pre-condition to Finance from Banks

      iii. Simultaneously work with Private Sector to mandate and give preference to Certified Cybersecure MSME Units in all procurements.

This can be modelled on NIST Cybersecurity Framework 2.0 for all businesses, starting with voluntary certification, gradually mandating Cybersecure-MSME Certification based on a layered approach (based on criticality of industry e.g. defense component manufacturers, BFSI etc.)

D. **MSME Sector Specific Cybersecurity Clinics:** Create MSME Cybersecurity Clinics with Government Grants and CSR: Provide digital support infrastructure for supporting MSMEs with cybersecurity advisory, implementation support, cybersecurity Incident handling support and response, On-Demand cybersecurity assessments, DPDP Implementation Support

E. **MSME Cybersecurity Awards:** Work with MSME Ministry, MeiTY, DSCI, FICCI, etc. to create sector-specific Cybersecurity Annual Awards. This would not only create awareness amongst MSMEs of importance of Cybersecurity but also encourage them to learn from peers in Industry.

   a. Besides Government can issue guidelines to provide special recognition to such MSMEs on their websites and extensive social media coverage

   b. Encourage and Foster Security-by-Design Manufacturing for all MSME units adopting Industry 4.0/5.0. In this direction work with Government to provide Cybersecurity Sandboxes and Testing Facilities for MSMEs.

F. MSME Cybersecurity Insurance : Work with Government for issue of directions to work with Government agencies and Insurers to create special Cybersecurity

Insurance packages for MSMEs at nominal cost (On the similar lines of DIGCI schemes and other PM Insurance Schemes etc.)

G. **Cybersecurity Capacity Building:** Work with MoF, MHA and Institutions such as AICTE, ICAI, ICSI,ICAI(Cost Accountants) to capacity building of Cybersecurity aware professionals for MSMEs

About the Author



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Sambath Parthasarathy is an alumnus of Indian Institute of Technology Delhi and Thiagarajar College of Engineering, Madurai. He earned his Ph.D. in Computational Fluid Dynamics and has built extensive experience as a Technology Solutions Consultant. Over the course of his career, he has worked with leading organizations such as IBM, Sun Microsystems, Silicon Graphics, and Centre for Development of Advanced Computing (C-DAC).

Sambath has consulted for clients in India and abroad in the areas of Artificial Intelligence (AI), Big Data Analytics, Design Thinking, GPU Programming, and High-Performance Computing (HPC). His primary interest lies in applying AI, Big Data on Cloud, Computer Vision, and Robotics to solve manufacturing industry problems.

As a guest faculty member at IITs, NITs, and Thiagarajar College of Engineering, he teaches industry-oriented computer science subjects with a strong emphasis on practical training and real-world projects. As a member of the Swadeshi Shodh Sansthan, T.N Chapter, he has been conducting AI workshops for college students and Faculty.

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