

Development and Assessment of Maturity Models for Industry 4.0 in the Indian Manufacturing MSME Sector

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ABSTRACT

Maturity models are vital for organisations in the Industry 4.0 age, facilitating assessing and improving their technological and procedural competencies. They assist in identifying areas of proficiency and establishing explicit objectives, allowing organisations to prioritise investments in technology, infrastructure, and talent efficiently. In an era where cyber risks and data security are crucial, these models are essential for risk mitigation, enabling firms to maintain competitiveness and resilience. A novel maturity model is presented for the Indian MSME sector, grounded in Baker's systematic approach and Nolan's Stage theories. The model delineates five maturation phases across ten dimensions, assessed using seventy-nine elements. The model underwent evaluation in a purposive sample study of 102 units from major manufacturing hubs to examine the maturity of manufacturing units in the MSME sector. The article presents the maturity results on multiple parameters like turnover, generation running the business, years of operation and types of manufacturing setup. The model serves as a thorough instrument for assessing an organisation's maturity level while also assisting practitioners in pinpointing essential areas for improvement and monitoring progress over time. It provides scholars with a comprehensive catalogue of dimensions and factors for assessing technological change, encompassing both the adoption of new technologies and the facilitation of substantial transition.

Keywords: *industry 4.0, maturity dimensions, maturity model, SME*

1. INTRODUCTION

Assessing maturity involves benchmarking against industry standards, setting achievable goals, and making informed decisions regarding technology investments and resource distribution. It is a powerful tool that empowers organisations to take control of their future. Evaluating the maturity level in adopting Industry 4.0 is crucial for

effective risk management, workforce development, and enhancement of operational efficiency. Gökalp E. *et al.* (2018) examine the model's capacity to assist firms in identifying potential risks, mitigating their effects, and developing targeted training programs to attract and retain skilled employees. Maturity models provide organisations with a systematic framework for assessing their current competencies and identifying opportunities for improvement (Pessl E. *et al.*, 2017; Stefan *et al.*, 2018; Basl, J., & Doucek, P., 2019). Maturity models assist organisations in recognising their areas of expertise and improvement opportunities, establishing attainable objectives, and developing a strategy for continuous advancement. Paulk, M. C. *et al.* (1993) examine how organisations can identify discrepancies and gain insights from those who have attained higher maturity levels by evaluating their maturity level. Akdil, K. Y. (2018) evaluates the necessity of maturity models to understand the extent of organisations' adoption of Industry 4.0.

The lack of a detailed maturity comprehension is identified as an area of research identified (Schumacher 2016; Adkil K.Y. 2018, Wang *et al.* 2019), which allows informed decision-making regarding technical investments, strategic planning, and resource allocation. Kagermann *et al.* (2013) assert that evaluating this growth level enables companies to benchmark their progress against industry standards, pinpoint areas for enhancement, and establish realistic objectives for future success. Further, Wang *et al.* (2019) identify the gaps in maturing to advanced technology, which can confer a competitive advantage to organisations by improving operational efficiency and augmenting existing capabilities through maturity level assessments.

Assessing the level of maturity of Industry 4.0 adoption on a structured framework is essential for effective risk management, as Rübmann *et al.* (2015) noted. Through

this understanding, businesses can identify potential risks, formulate strategies to address them, assess concerns related to cybersecurity, data privacy, and operational disruptions, and allocate resources efficiently. The maturity level of Industry 4.0 adoption is essential for the effective management and development of the workforce. Kagermann *et al.* (2013) assert that it assists companies in creating targeted training programs and initiatives by identifying essential skills and competencies required for the future workforce. Schumacher (2016) states that the readiness assessment takes place before initiating the maturing process, whereas the maturity assessment aims to evaluate the current state during the maturing process. Understanding an organisation's current maturity level is essential, particularly during a critical phase of adopting new technologies.

Progressing along the maturity trajectory of Industry 4.0 is crucial for MSME units and positions them as significant players in this technological revolution. By utilising data analytics and real-time information, MSMEs can make informed decisions that enhance operational efficiency and strategic planning (Bahulikar *et al.*, 2022; Sordan *et al.*, 2022). Industry 4.0 facilitates the integration of supply chain operations with external partners, enhancing collaboration and communication. De Vass *et al.* (2021) examine how this link may produce significant performance benefits and improve supply chain resilience. While product diversity may complicate supply chain management, it simultaneously necessitates the development of more efficient processes and systems (Huddiniyah, E., & ER, M. (2019). Flexibility in the supply chain is crucial (Daultani, Y 2015) for fulfilling customer demands, necessitating the introduction of innovative technology. MSME units implement lean practices to achieve flexibility; however, they do not comprehend the connection between lean methodologies and Industry 4.0. Incorporating lean manufacturing in MSMEs can substantially enhance efficiency, quality, and competitiveness, rendering it a beneficial strategy for these firms (Buer V. *et al.*, 2018; Bahulikar *et al.*, 2023). The proposed maturity model addresses the gaps cited in the literature with a generalisable model applicable in multiple manufacturing contexts.

2. LITERATURE REVIEW AND BACKGROUND

The existing academic models, which are not just theoretical constructs but practical tools, can be categorised into two main types: literature reviews (Mittal *et al.*, 2018; Sony & Naik, 2019)

and conceptual frameworks (Ganzarain & Errasti, 2016; Agca *et al.*, 2017; Gökalp *et al.*, 2017; Basl & Doucek, 2019; Trotta & Garengo, 2019; Hajoary *et al.*, 2023). Additionally, some conceptual papers include discussions of case studies (Schumacher *et al.*, 2016; Ustundag *et al.*, 2018; Santos & Martinho, 2020; Wagire *et al.*, 2021). Consulting firms and industry practitioners have created models for assessing Industry 4.0 maturity or readiness, including The Connected Enterprise Maturity Model (Rockwell Automation, 2014). IMPULS–Industrie 4.0 Readiness (2015); Industry 4.0 / Digital Operations Self-Assessment (PwC, 2016); The ACATECH Industry

4.0 Maturity Index (2017); Singapore Smart Industry Readiness Index (2018).

Academic literature has primarily concentrated on Smart Manufacturing (Meindl *et al.*, 2021), overlooking the multidimensional aspects of Industry 4.0. We analyse the six primary models for evaluating the readiness and maturity of Industry 4.0 to formulate the Industry 4.0 maturity model for Indian MSMEs within the OEM supply chain. This is significant as it provides a generalised approach for multiple sectors, addressing the unique challenges and opportunities they face in adopting Industry 4.0. The models differ in scope, evaluation criteria, and features to address various industries' varied needs and applications.

The model is built akin to stage theories (Nolan 1973), which help develop knowledge in diverse fields. The capability maturity model is the first readiness model in practice, describing maturity level as a well-defined evolutionary plateau. This model helps organisations identify their strengths and weaknesses, establish attainable goals, and plan continuous improvement. Industry 4.0 is considered the new maturity stage in manufacturing companies, which is required for developing the ecosystem. The interdisciplinary study considers technology maturity, organisation theory, and economic system elements. The model is developed following Hevner *et al.*'s (2004) design science approach and Becker's (2009) methodical process, with additional enhancements. The development process involves systematic literature research, expert interviews, conceptual modelling, validations, and field testing.

Maturity models are essential for assessing an organisation's readiness for Industry 4.0, but they have limitations. Indian MSMEs face challenges due to their approach, functioning, offerings, services, and environment. Bahulikar *et al.* (2022) examined factors affecting technology adoption in India, identifying deficiencies in current models and advocating for a new model. This proposed model is a collaborative effort designed to include strategies for transitions, technology integration, adoption of emerging technologies, human resource development, and effective data utilisation for decision-making. A well-developed Industry 4.0 ecosystem should include an interconnected system, prioritising customer requirements, and cultivating an organisational culture that aligns with end-user needs. The proposed maturity model consists of ten layers representing the organisation's value stream. The Industry 4.0 Maturity Model comprises five levels, each with a distinct degree of development. The model eliminates subjective influences and employs a standardised approach. The assessment reaches stage five if all components can forecast and work together.

3. DEVELOPMENT OF A MATURITY MODEL FOR INDIAN MSMEs

The methodology employed entailed conducting semi-structured interviews with the sample manufacturing MSMEs. The purpose was to gain insight into their existing state and identify the elements that contribute to or hinder the implementation of Industry 4.0. Based on the case study inputs and literature, the authors have defined ten

dimensions of maturity, which are crucial to comprehend from the perspective of manufacturing domain MSMEs in the OEM supply chain.

3.1 Maturity Dimensions

The proposed maturity model consists of ten dimensions representing the organisation's complete value stream, as shown in **Table 1**. Additionally, each dimension encompasses multiple elements that are required to be assessed. The elements of maturity and their dimensions were established through an initial case research study done with manufacturing MSME units and by examining relevant literature and expert opinion. The ten dimensions are assessed based on seventy-nine essential elements, as shown in **Table 1**, which are crucial for migrating MSMEs to Industry 4.0. In addition, these levels and dimensions balance technical accuracy and usefulness when describing the intermediate steps and ultimate goals an organisation needs to keep improving as it moves towards Industry 4.0.

3.2 Maturity Stages

A five-point maturity stage assessment assesses a company's maturity level, as shown in **Figure 1**, which is proposed and validated. The five layers of maturity are layer one, which is the beginning phase, where an organisation possesses limited competencies in the field of Industry 4.0. Conversely, the highest layer signifies a comprehensive understanding of complete adulthood. Progressing throughout the evolutionary spectrum entails continually advancing an organisation's capabilities or process performance. The maturity model is the metric for evaluating the location on the evolutionary trajectory. The document outlines the requirements and features that must be met to achieve a specific level of maturity. During a maturity evaluation, an assessment is conducted to evaluate the organisation's current state based on specific criteria. The identified attributes are assessed to determine the suitable level of maturity for the organisation.

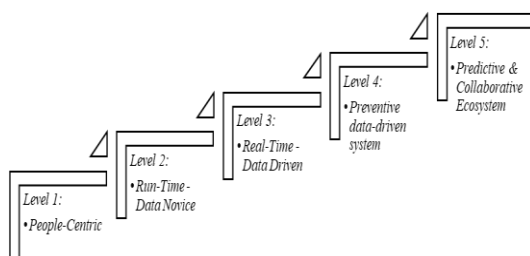


Figure 1 Five stages of maturity

The first maturity level of an organisation is characterised by a focus on people and a need for a data culture. In the second stage, the company becomes a data neophyte and transitions to implementing real-time data management. At the third level of maturity, the organisation implements a data-centric approach where data is consistently gathered and processed. In the fourth stage, data is transformed to generate predictive decisions. At the pinnacle of maturity, companies operate within a predictive ecosystem that spans the whole value chain.

3.3 Elements of Maturity Dimensions

The strategy dimension includes business strategy, growth plans, product portfolio, manufacturing processes, supply chain integration, Industry 4.0 implementation roadmap, resource allocation, leadership acceptance, management conviction, technology awareness, and business ecosystem for I4.0 deployment. The Business Process dimension comprises various processes such as business, design, product development, marketing, and manufacturing processes. The customer dimension of maturity assessment involves customer integration, requirement mapping, expectation mapping, data utilisation, and customer connectivity. The maturity assessment's product dimension includes customer need mapping, product life cycle management, product feature management, product variety management, digitalisation, and product integration with other products.

The reduction dimension outlines I4.0's application in functional areas such as data management, machine connectivity, communication, networking, ICT infrastructure, man-machine interfaces, flexibility for small batches, infrastructure flexibility, material flow, production planning, plant capacity mapping, utilisation mapping, and plant maintenance. The Technology Use dimension assesses the appropriate use of technology applications, including autonomous robots, simulation, system integration, Industrial Internet of Things (IIoT), cybersecurity, cloud, additive manufacturing, RTLS, RFID, sensors, actuators, and mobile technologies. It also covers the technology, automation, simulation, and integration life cycle. The Cyber dimension highlights the importance of ICT in organisations, focusing on data management within and outside the organisation, interoperability, data analytics, mobile connectivity, data security, and knowledge repositories for capacity mapping, interoperability, and data sharing.

The Supply Chain dimension, crucial for Industry 4.0, encompasses understanding customer requirements, supplier communication, information sharing, and logistics processes. The Communication dimension for maturity encompasses vertical data management, data collection and storage technologies, predictive quality and product reliability, internal manufacturing process agility, business process flexibility, and decision-making layers. The People dimension is the critical maturity area, encompassing Industry 4.0 awareness, need identification, technology awareness, implementation capabilities, and skill. **Table 1** shows the ten dimensions and its seventy-nine elements of maturity.

3.4 Survey

The comprehensive survey is conducted through a structured questionnaire aimed to assess the level of Industry 4.0 maturity in Indian MSMEs. The study focused on three major industrial hubs in India, which are representative clusters of major identified sectors: the Southern region (Chennai, Coimbatore, and Belagavi), Northern India (National Capital Region and Rudrapur), and two states from Western India, namely Gujarat (Ahmedabad, Rajkot) and Maharashtra (Aurangabad, Pune, Mumbai, and Kolhapur) to make maturity the model generalisable. The purposive sample also consisted of

MSMEs using various manufacturing processes, encompassing different levels of business turnover and years of operation while ensuring the sample represented the organisation's management pattern, which may impact decision-making regarding technology upgradation. The sample population, a highly representative group of 102 MSMEs in the Indian manufacturing setup, was selected to ensure diversity, with a significant affiliation with major

OEMs as part of their supply chain. The samples selected also represent the population in terms of business value, talent requirements, infrastructure, and technology, all of which contribute to developing a robust framework. The purposive sample ensures the survey results are generalisable and capture feedback from various manufacturing MSME units

Table 1 Dimensions and elements of maturity

Dimension	Elements
Strategy	Business Strategy; Growth Plans; Product Portfolio; Manufacturing Processes; Supply Chain Integration; I4.0 Implementation Roadmap; Resource Allocation for I4.0; Leadership acceptance for I 4.0; Management Conviction on I 4.0; Technology Awareness of I4.0; Business Ecosystem for deployment
Business Process	All Business Processes; Design; Product Development ; Marketing ; Manufacturing
Customer	Customer Integration; Requirement Mapping; Expectation Mapping; Utilisation of Customer Data; Connectivity with customer
Product	Customer Need Mapping; Product Life Cycle Management; Product Feature Management; Product Variety Management; Digitalisation of Products; Integration with Other Products.
Production	Data Management in Production; Machine Connectivity and communication; Networking across Plants; Infrastructure in production; Man Machine Interfaces; Flexibility to handle small batches; Infrastructure Flexibility for managing variety; Material flow in Organisation; Production Planning; Plant Capacity Mapping; Plant Utilisation Mapping; Plant Maintenance
Technology	Selection Of Technology; Life Cycle of Technology; Autonomous Robots; Simulation; Horizontal and Vertical System Integration; The IoT; Cyber security; The Cloud; Additive Manufacturing; RTLS & RFID; Sensors and Actuators; Mobile Technologies
Cyber	Importance of ICT in Organization; Data Management within the Organisation; Data Management Outside organisation; Data Management between Group companies; Use of data for capacity mapping; Use of data for interoperability; Platforms to share data; Use of data Analytics; Mobile connectivity in operations; Security of data; Knowledge Repositories;
Supply Chain	Understanding Customer Requirements, Customer Communication, Supplier Communication process Information sharing with suppliers, Logistics Process, Internal Process Layer
Communication	Technologies of collecting and storing data; Use of data for predictive quality; Use of data for predictive product reliability; Agility of internal manufacturing processes; Flexibility of business process; Decision-making layers
People	Awareness on Industry 4.0; Need Identification; Technology Awareness; Implementation Capabilities; Skill

4. RESULTS AND DISCUSSION

The surveyed MSME units, as seen in the box plot of **Figure 2**, show a low level of maturity on all the dimensions and are in the range of Level 1 of people-centric to Level 2 of data novice; further, the dimensions like people and cyber show the lowest level of maturation. Dimensions of Customer shows a relatively higher maturity amongst the surveyed units. The gaps to mature from Level 1 to Level 4 of the Preventive data-driven system and further to Level 5 of the Predictive and Collaborative Ecosystem require a good understanding and a structured approach to Industry 4.0 implementation in the transition journey.

The survey data indicates that the customer dimension is the most developed in organisations across ten tiers and seventy-nine variables. This is followed by the business process dimension and communication (IBP). However, the dimensions of Strategy, Technology Use and Cyber, along with people, exhibit a very low median of maturity, which is below 1.5, indicating the novice state of the organisation. There are a few outliers in the respondent group who show a maturity of preventive data-driven systems. Further, we will conduct an analysis of survey data to understand the current state of maturity in different dimensions.

4.1 Maturity Segmentation by Each Dimension

Figure 3 shows the histogram analysis of the organisation's maturity in each dimension. We analyse the maturity level of participating MSMEs in the first phase on the ten dimensions and present the results. The maturity dimensions are left skewed, showing majority of the participating units fall in the lower stage of maturity with a standard deviation of around 0.5 units. **Figure 4** shows the maturity level of MSME units on each dimension of maturity. It is seen to be significantly low on each dimension and falls in a maturity level of one to two.

4.1.1 Strategy

The strategy element includes business strategy, growth plans, product portfolio, manufacturing processes, supply chain integration, Industry 4.0 implementation roadmap, resource allocation, leadership acceptance, management conviction, technology awareness, and business ecosystem for I4.0 deployment for evaluation. The survey result reflects the overall maturity level of the participant MSME units, which is on the lower side of the strategy dimension. The strategy has a mean of 1.8922, reflecting a nascent stage of maturity on the dimensions of strategy and the distribution is skewed towards the lower side of maturity. The primary component is that of Business

Strategy. The surveyed organisations established, recorded, and internally disseminated the business strategy. Regarding the Growth Plans, the surveyed organisations

indicated that the Growth Plan is developed, recorded, and disseminated internally, also the product portfolio has been defined and designed.

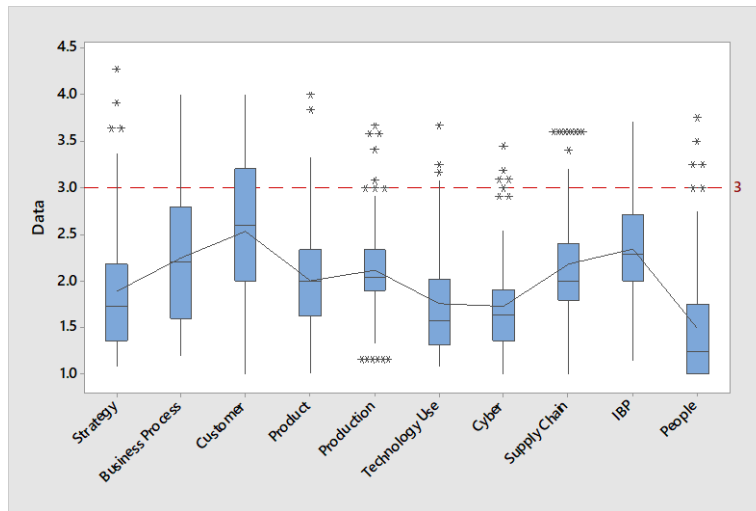
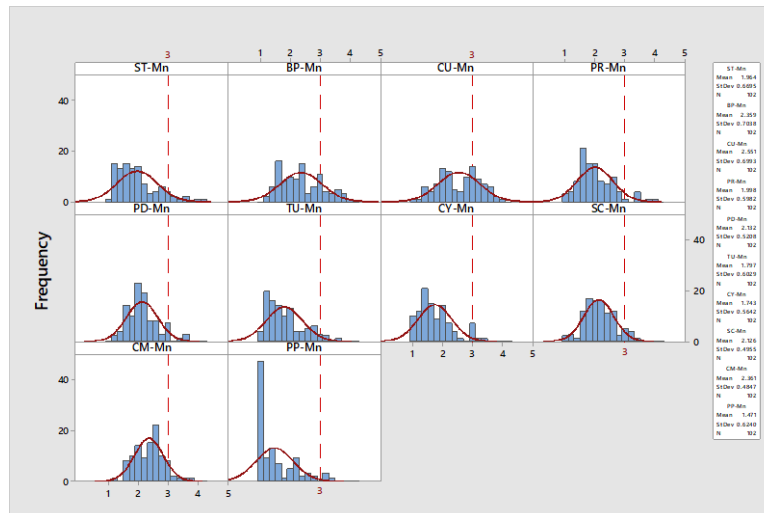


Figure 2 Maturity level on ten dimensions of maturity



Variable	ST-Mn	BP-Mn	CU-Mn	PR-Mn	PD-Mn	TU-Mn	CY-Mn	SC-Mn	CM-Mn	PP-Mn
Mean	1.96	2.36	2.55	2	2.13	1.8	1.74	2.13	2.36	1.47
StDev	0.67	0.7	0.7	0.6	0.52	0.6	0.56	0.5	0.48	0.62

Figure 3 Dimension-wise spread of maturity level on ten dimensions of maturity

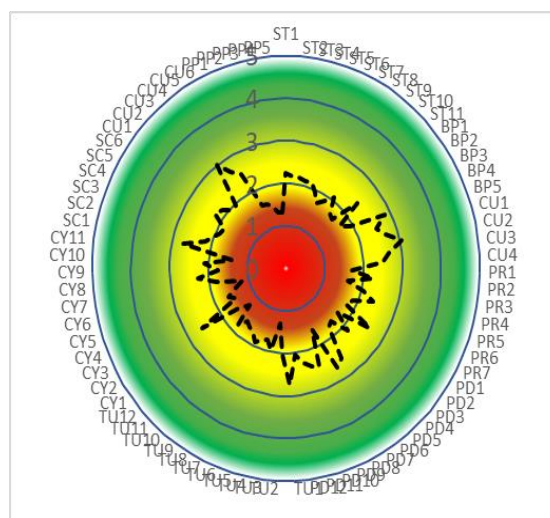


Figure 4 Average maturity level on each dimension (elements as per table 1)

Regarding the manufacturing procedures, most MSMEs utilise CNC machines for production. These machines operate independently and are not connected. The organisation has a clearly defined and effectively communicated supply chain strategy as a component of Supply Chain Integration. The MSME units are located on the second level of the Industry 4.0 Implementation Roadmap. At this stage, the organisation clearly understands the need for implementation, but the specific roadmap for implementation is still unknown. The skill and technological gaps in resource allocation for Industry 4.0 currently need to be discovered.

The survey of the MSME units revealed a widespread acceptance of leadership for Industry 4.0 across different departments. The leadership also has a high level of awareness, as they recognise the importance and benefits of implementing Industry 4.0. The management is fully convinced of the application and advantages of Industry 4.0, and they view the benefits as a direct result of deploying this technology. The survey indicated a low score for the Technology Awareness component of Industry 4.0. Additionally, the team needs to gain awareness of Industry 4.0 technologies, which is consistent with the overall need for more understanding of Industry 4.0 concepts within the ecosystem.

4.1.2 Business Processes

The Business Process exhibits a mean value of 2.2529. The distribution of this process follows a normal distribution and has a significant degree of variability. Within business processes, the initial component is the actual business process itself. The MSME units have surveyed and established the Business Process, and the Design has been done based on specific needs. Regarding Product Development Processes, the MSMEs exhibited a maturity level of two, indicating that the Product design is derived from client specifications. The marketing processes involve a forecast-driven process divided into weekly delivery buckets. On the other hand, the Manufacturing Processes demonstrate the ability to prepare for Small Batches, and the machines can quickly change.

4.1.3 Customer

Conversely, the Customer dimension exhibits a mean of 2.5294, displaying two distinct peaks that suggest the presence of two separate categories within the sample, each with a different perspective on the customer dimension. The MSMEs agree that customer integration is necessary for successful decision-making. The necessity of Requirement Mapping is also recognised, as it involves regularly communicating the customers' requirements to internal stakeholders in the participating MSMEs. The MSMEs have reached a degree of maturity in mapping client expectations, which are regularly captured. However, the utilisation of customer data is at a low level. The organisation has recognised the need to obtain customer data, but it has yet to be used effectively. The connectivity with the consumer is provided as per their specific requirements.

4.1.4 Product

The product dimension of maturity has an overall mean of 2; nevertheless, the distribution is skewed towards the lower side of maturity. The initial component focuses on Customer Need Mapping, which currently has a low level of maturity. Customer need mapping is conducted frequently to develop product designs, but the product life cycle still needs to be mapped. However, mapping the customer touch points requires effort, as these MSMEs are periodically mapped to incorporate additional features within the product. The MSMEs are transitioning to Product Variety Management by implementing a Batch Production culture. Regarding the digitalisation of products, the items are primarily designed to fulfil fundamental needs, but there needs to be more integration with other products despite the possibility of integrating them.

4.1.5 Production

The production dimension consists of twelve elements in the maturity assessment, with a mean value of 2.1136. However, the distribution is biased towards lower levels of maturity, indicating that most of the elements in this component are at a lower level of maturity. The initial aspect of data management in production reveals that data storage for documentation lacks real-time capability and machine connectivity and communication inside the MSME. The maturity of the networking units in different plants is evident in the information transmission method, which mainly occurs through mail or telecommunication. Similarly, in the production ICT infrastructure, information exchange relies on mail or telecommunication since the man-machine interface utilises local user interfaces.

Nevertheless, MSMEs exhibit remarkable adaptability in managing tiny batches since they can utilise adaptable manufacturing systems and standardised components and infrastructure. Flexibility in managing variation is attained through tools such as SMED, which are employed to accommodate changes in the type of part produced. However, the machines are not interconnected, and the material flow within the organisation is done in batches. The Production Planning is carried out daily, in real-time, and is subsequently transformed into production schedules. The Plant Capacity Mapping is conducted for the surveyed MSMEs using cycle times mapped at both the part and machine levels. The Plant Utilisation is specified and mapped manually. The Plant Maintenance department utilises Preventive Maintenance tools to ensure optimal performance and longevity of equipment.

4.1.6 Technology Use

The participating MSMEs demonstrate a relatively low level of technological maturity, with a mean of 1.7606 across all twelve factors. Furthermore, the maturity level is predominantly biased towards the lower end. The increased level of maturity in the first dimension of the selection of technology units is mainly attributed to the selection process, which is based on customer demand and meeting computerisation requirements. Units must have a clear understanding of the life cycle of technology and the trends in product life cycles before making any investments, as this can have a significant financial impact.

However, the units need to gain knowledge about Autonomous Robots and understand simulation tools.

The MSME units have real-time information exchange among departments as a horizontal and vertical system integration component. The participating units demonstrate a low level of maturity regarding the Industrial Internet of Things (IIoT), as the organisation needs more awareness. Additionally, implementing a secure internal network layer for cyber security is at a lower maturity level. Interestingly, the units strongly understand The Cloud, which is widely used for data storage. The units know the concept, application, and usage of additive manufacturing in the field. The units are knowledgeable about Radio Frequency Identification (RFID) but now rely on manual monitoring to track items during transportation and manufacture. The manual system tracks the receipt and issue of raw materials. Machines operating on preventative and breakdown repair processes lack the presence of sensors and actuators. The participating units need to gain awareness of mobile technologies and utilise them to map data across the value chain.

4.1.7 Cyber

The participating units have a relatively low degree of cyber capability, with a mean score of 1.7264. Once again, the histogram exhibits a left skew, indicating a generally low level of maturity. Concerning the significance of Information and Communication Technology (ICT) in the organisational cyber element, the units have a low level of maturity and a need for more awareness of the importance of ICT. This is also the situation with data management inside the organisation. Once again, the MSMEs collect and store the data as soft records in repositories but need to assess it for further enhancements.

The Data Management Outside the organisation component needs to exhibit a better level of maturity, as it fails to acquire data from external stakeholders. Additionally, the effectiveness of data management within group firms is hindered by each company maintaining its separate data. Data is not utilised for capacity mapping, as capacity mapping is performed manually. Since the Machines are used independently, data needs to be improved for interoperability. The data is collected, and information is communicated as needed without sharing platforms. The captured data is processed and transformed into information in a small number of MSMEs, and the machines have the potential to be connected. Data security is compromised due to the inadequate implementation of security firewalls, the lack of knowledge repositories, and the lack of knowledge banks.

4.1.8 Supply Chain

The supply chain histogram follows a normal distribution, with the participating MSMEs showing a somewhat higher maturity level than other dimensions. Some MSMEs exhibit even higher maturity levels, resulting in a higher mean maturity level overall. The mean of the Supply Chain variable is 2.1824, which is relatively high compared to other dimensions of maturity. The maturity level of Understanding Customer Requirements indicates that customers communicate their requirements every month. However, the communication between the customer

and supplier is limited to emails and phone calls, which requires more efficient data exchange.

The participating MSMEs demonstrate a higher level of maturity regarding information sharing with suppliers since the exchange of information between the MSMEs and their suppliers is proactive. The logistics parts receive a low score due to the significant level of human interaction necessary to communicate information among stakeholders, as organisations need more horizontal integration compared to a horizontally integrated system.

4.1.9 Communication

The participating MSMEs exhibit a slightly higher level of maturity, with the communication element showing an average maturity level of 2.1824 across seven communication elements. Additionally, the distribution of the supply chain histogram follows a normal distribution. In the communications domain, the vertical data management component displays a trajectory of improvement as the significance and necessity of data are comprehended. However, it is worth noting that the data capture process occurs in isolation. Regarding data collection and storage technologies, MSMEs employ manual record keeping, while data is saved in computers as a centralised repository at the departmental level.

Data for predictive quality is absent, as the manual data gathered throughout processes is evaluated reactively to comprehend the reasons behind failures rather than for prediction and prevention. Using previous product failure data to optimise products indicates a poor level of maturity in adopting a proactive approach to predicting product dependability. Regarding the agility of internal manufacturing processes, the MSMEs have a high level of maturity as the internal processes are designed to produce small batches and have long changeover periods. The flexibility of business processes is moderately mature since they have limited flexibility, and decision-making is centralised to mitigate unforeseen impacts. In most MSME units, the decision-making layer exhibits a low level of maturity due to the centrally controlled decision-making process employed in the MSME sector.

4.1.10 People

The histogram exhibits a highly pronounced left skewness, indicating a generally low level of maturity on this axis. Among the surveyed MSMEs, the people element demonstrates the lowest overall maturity level, with a mean value of 1.4926. The individuals' degree of maturity regarding their understanding of Industry 4.0 could be much higher. Only a few individuals have participated in training sessions on Industry 4.0 tools and technologies. However, this particular aspect has received the highest score within this dimension.

In terms of other dimensions, such as Need Identification, the level of maturity could be higher due to users' lack of knowledge about the usage and benefits of Industry 4.0, which is also evident in their lack of Technology Awareness. The lack of familiarity with the technologies utilised in the Industry 4.0 ecosystem, and their influence on business decisions hinders the level of maturity. The teams in the participating MSMEs need to gain awareness of the implementation roadmap for Industry

4.0. Additionally, they need more exposure to automation, resulting in a low skill level for deployment. The low maturity level exhibited by MSMEs is due to their limited exposure to the technologies and tools used in the Industry 4.0 ecosystem.

4.2 Significance

To understand if the dimensions and elements of maturity are significant in relation to the demography of the participating MSMEs, we conducted a Kruskal-Wallis test. The results are shown in **Table 2**. The Kruskal-Wallis test is a rank-based nonparametric test that can be used to

determine if there are statistically significant differences between and check the significance of the maturity layers.

The results show no significance of the maturity level with the type of manufacturing, the location of the business, the type of ownership, or the number of years the entity has been in business for a few elements of Strategy, Technology, and Production in the dimension of maturity of the generation running the business. The turnover of the organisation shows a significance on maturity. In contrast, the rest of the dimensions do not show significance on the organisation's maturity level and the elements of maturity.

Table 2 Kruskal-wallis significance

Type of Industry					Ownership				Generation			
	IS	S	K	CSq	IS	S	K	CSq	IS	S	K	CSq
ST	11	0	8.51	15.51	11	0	1.87	5.99	4	7	6.72	5.99
BP	5	0	7.49	15.51	5	0	1.33	5.99	5	0	1.26	5.99
CU	3	2	12.52	15.51	5	0	0.98	5.99	5	0	2.39	5.99
PR	6	0	6.6	15.51	6	0	0.78	5.99	4	2	4.87	5.99
PD	12	0	6.8	15.51	11	1	2.26	5.99	8	4	4.52	5.99
TU	12	0	6.18	15.51	11	1	2.09	5.99	6	6	6.44	5.99
CY	11	0	6.16	15.51	11	0	1.37	5.99	9	2	3.96	5.99
SC	6	0	6.66	15.51	5	1	2.09	5.99	6	0	2.98	5.99
CM	6	0	6.59	15.51	6	0	0.91	5.99	6	0	2.47	5.99
PP	5	0	8.6	15.51	5	0	1.17	5.99	5	0	1.72	5.99
Years of Business					Turnover				Region			
	IS	S	K	CSq	IS	S	K	CSq	IS	S	K	CSq
ST	11	0	3.03	7.81	5	6	5.9	5.99	11	0	6.28	18.31
BP	5	0	1.24	7.81	4	1	3.48	5.99	4	1	9.05	18.31
CU	4	1	4.41	7.81	2	3	4.04	5.99	5	0	12.16	18.31
PR	6	0	4.44	7.81	5	1	3.87	5.99	6	0	11.19	18.31
PD	12	0	2.21	7.81	7	5	7.47	5.99	12	0	9.48	18.31
TU	12	0	1.9	7.81	2	10	8.99	5.99	12	0	10.27	18.31
CY	11	0	2.26	7.81	3	8	8.04	5.99	11	0	8.75	18.31
SC	6	0	3.1	7.81	4	2	4.82	5.99	6	0	8.01	18.31
CM	6	0	2.52	7.81	4	2	4	5.99	6	0	7.14	18.31
PP	5	0	1.33	7.81	3	2	5.01	5.99	5	0	7.03	18.31

I-Insignificant, *S*-Significant, *K*-Avg K Value, *CSq*- Chi-square

4.3 Maturity Segmentation on Type of Industry

Figure 5 shows the box plot analysis of the maturity by type of industry. The surveyed industries are at varying levels of advancement towards Industry 4.0. Cities such as Aurangabad, Belagavi, Chennai, Ahmedabad, Rajkot, Mumbai, Pune, and Rudrapur are transitioning from having limited knowledge of data to adopting a data-driven approach. Coimbatore is transitioning from a data-centric approach to adopting proactive systems. Kolhapur is shifting its focus from being centred around people to becoming inexperienced in handling data. Nashik and NCR are transitioning from a focus on individuals to embracing data-driven approaches. The industries can be categorised as laggards in strategy and technology, while they perform better in business processes. They are lagging in cybersecurity and people management but are ahead in customer maturity.

The rubber industry demonstrates exceptional proficiency in business operations, client contentment, product efficacy, manufacturing, technology implementation, and communication. The advancement of mechanical sub-assemblies and non-ferrous casting and machining techniques have reached a more sophisticated level. The technology, supply systems, and communication mechanisms employed in plastic processing and tool production have advanced significantly. Each industry is currently at varying degrees of advancement towards Industry 4.0. More precisely, the organisations in the foundry and machining are advancing from a beginner in data analysis to mastery in making data-based decisions and transitioning from a methodology that relies on data analysis to a proactive approach in the electronics and electrical industry. Assemblers of mechanical components are moving from a beginner in data analysis to mastery in data-based decisions.

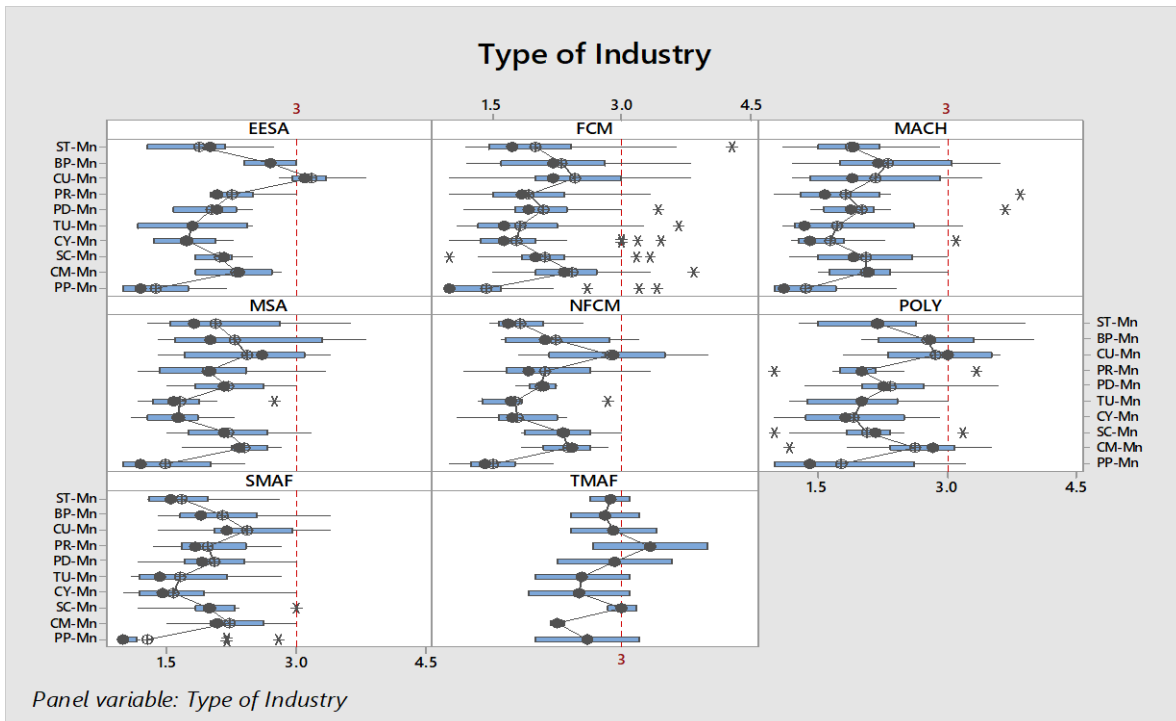


Figure 5 Maturity by type of industry
 EESA- Electrical and Electronic Sub Assemblies, - FCM- Ferrous Casting, MACH – Machining, NFCM – Non-Ferrous, POLY – Polymers, SMAF – Sheet Metal and Fabrication, TMAF – Tool Manufacturing

4.4 Maturity Segmentation by Industry Age

Figure 6 shows the box plot analysis of the maturity by age of the industry. MSME units with a duration of less than three years or newly established businesses are shifting their emphasis from human resources to data analysis. A similar shift occurs for MSMEs that have been operational for 3 to 10 years and those that have been in operation for 10 to 25 years. MSMEs with over 25 years of experience are shifting from being novices with data to becoming data-driven. This indicates that startups and businesses with over twenty-five years of existence demonstrate a significant level of maturity in terms of Industry 4.0, surpassing other MSMEs. Nevertheless, the overall level of all the MSMEs remains within the lower mid-range of maturity. Startups have a well-defined strategy that experiences setbacks over several years. Nevertheless, a long-term strategy has been implemented to ensure the sustainability of MSMEs for a period exceeding 25 years.

As the industry advances, the efficiency of corporate procedures increases. Startups and established MSMEs prioritise customer orientation. Startups possess a significant number of well-developed goods for Industry 4.0, surpassing those that have been in operation for more than twenty-five years. The production layer improves significantly during years of operation. The efficacy of technology utilisation is enhanced with the passage of time and experience; also, the efficacy of cyber security increases over time. The quality of communication improves as the years progress. Startups prioritise human capital and experience attrition over time.

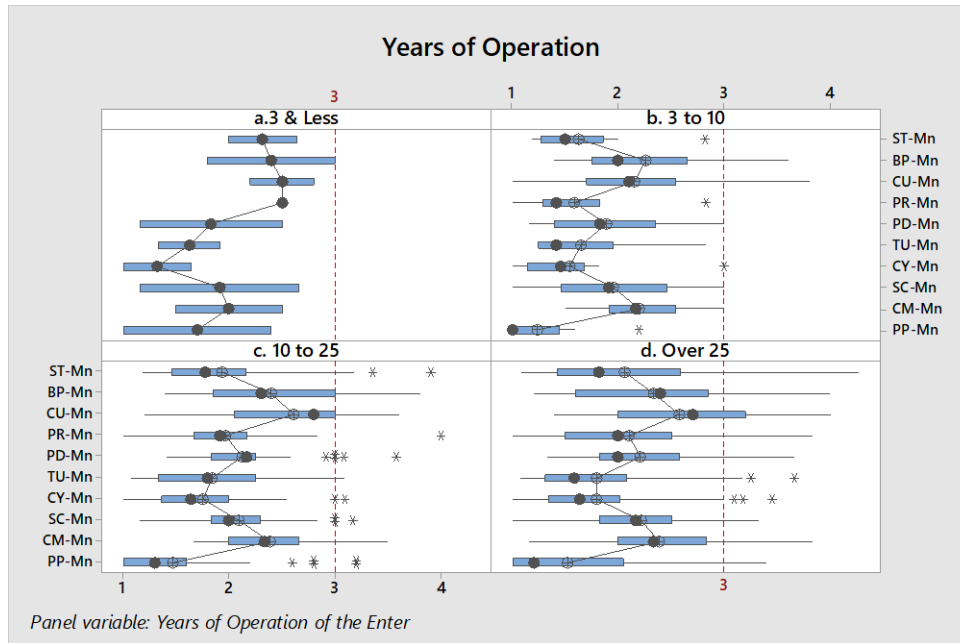
4.5 Maturity Segmentation by Business Turnover

Figure 7 shows the box plot analysis of the maturity by industry age. Companies with a turnover of up to 50 Mn

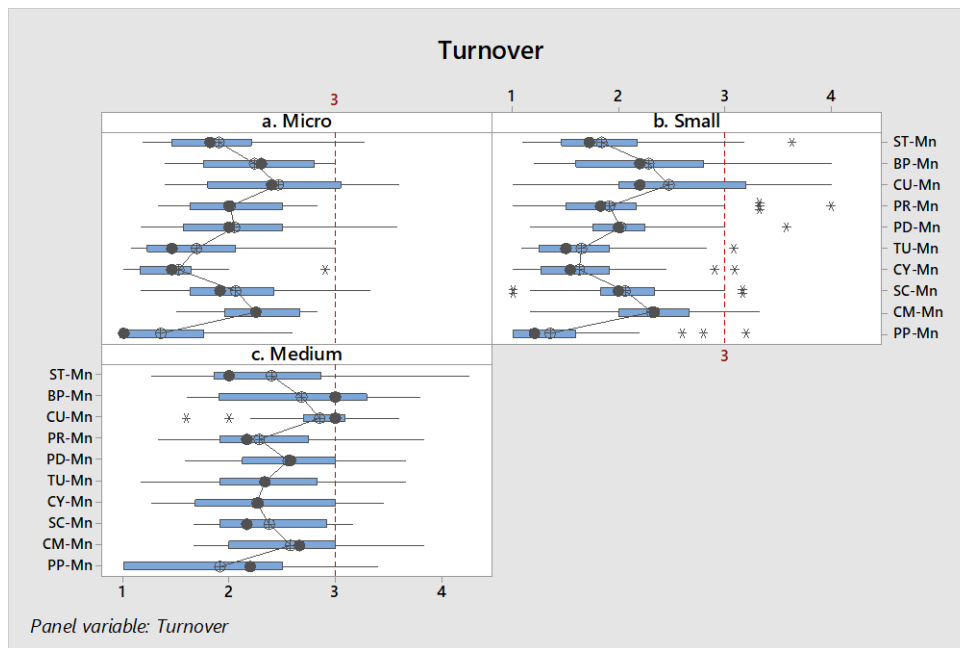
INR are transitioning from a people-centric approach to being less knowledgeable about data. Similarly, companies with a turnover of more than 50 Mn and up to 750 Mn INR are also moving from a people-centric approach to being less knowledgeable about data. However, companies with a turnover of more than 750 Mn INR and up to 2500 Mn INR are transitioning from being less knowledgeable about data to becoming data-driven.

Micro and small units lag in the strategic layer, although their maturity improves as turnover increases. All organisations demonstrate a comparable level of business process maturity, which escalates in tandem with the size of the business. All organisations demonstrate a similar level of customer maturity, which proportionally grows with the size of the business.

All the participating MSMEs are at a beginner level in creating an industry. For products fully compatible with version 4.0, Organisations with a high turnover can develop more efficient manufacturing processes compared to those with less turnover. Organisations with low turnover possess less capacity to invest in technology than those with high turnover. The capacity of small organisations to invest in cybersecurity is limited, and it grows in tandem with the organisations' turnover. Organisations with minimal employee turnover are nimbler and exhibit a higher level of maturity. Communication is enhanced when the rate of employee turnover rises, and organisations with more turnover exhibit a greater maturity with the turnover of the organisation. Organisations that experience considerable employee turnover tend to have a comparatively greater level of maturity.



a - Less Than 3 Years, b- 3 years to 10 years, c- 10 years to 25 years
Figure 6 Maturity by years of operation of the organisation



a-Micro Enterprise, b- Small Enterprise, c- Medium Enterprise
Figure 7 Maturity by turnover of the organisation

4.6 Maturity Segmentation by Ownership

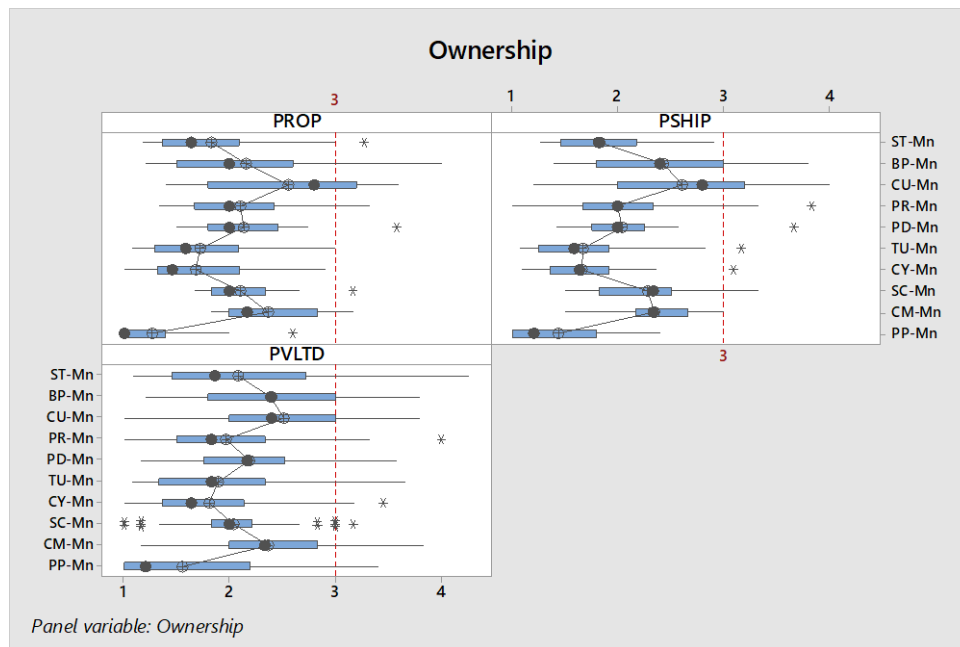
Figure 8 shows the box plot analysis of the maturity by the age of the industry. All the ownership categories, which include proprietorship, partnership and private limited companies that fall under the MSME sector, exhibit a low level of maturity compared to the MSMEs' turnover dimension.

Here again, the MSMEs exhibit a relatively higher level of maturity in the communication and customer elements of maturity, followed by internal business processes. The MSME units do not show a differentiated trend by ownership regarding the cyber layer, which falls on the lower level of maturity. As in all other

demographic slicings, the people layer again exhibits the lower layer of maturity across all the ownerships in an MSME setting.

4.7 Maturity Segmentation by Generation Running Business

Figure 9 shows the box plot analysis of the maturity of the generation running businesses. The analysis of data reflects an interesting pattern on the maturity of the organisation and the generation which is running the business; the MSME units, which are run by the third generation, reflect a higher level of maturity; this may be attributed to the fact of business stability and capability to absorb shocks in business and the acceptance of new technologies by new generation leaders. The third generation's strategy element is also at a higher level of maturity.



Prop – Proprietary, PSHIP – Partnership, PVLTD- Private Limited
Figure 8 Maturity by ownership

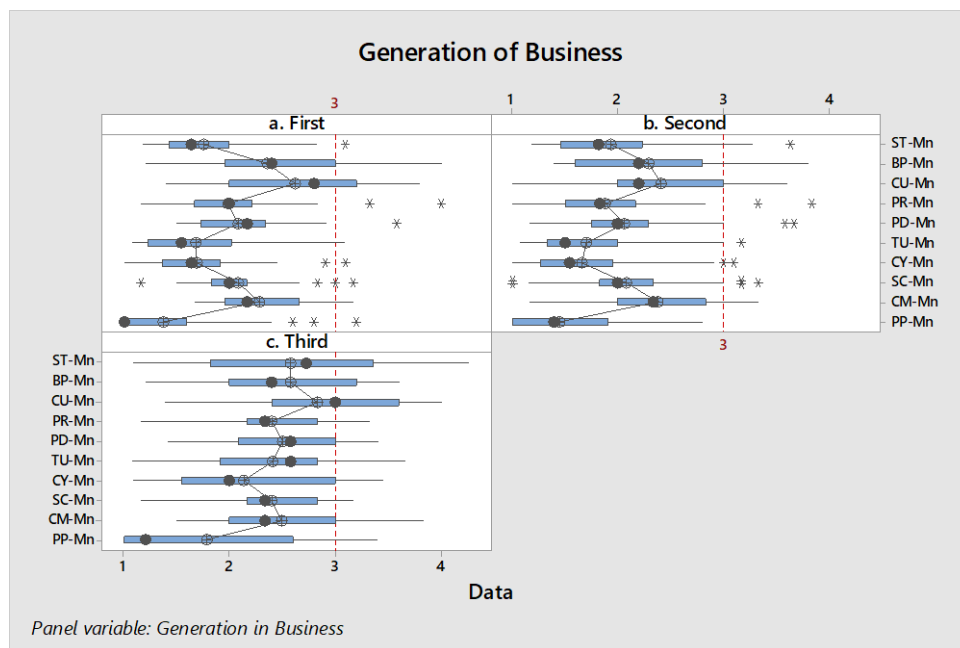


Figure 9 Maturity by generation running business

5. CONCLUSION

Maturity models are vital instruments for organisations in Industry 4.0. They facilitate the evaluation and improvement of their technological and procedural competencies. Further, they assist companies in identifying areas of expertise, setting objectives, and planning and distributing expenditures in technology, infrastructure, and human resources. Maturity models can also enhance the efficient allocation of resources and prioritise essential competencies for digital transformation. The proposed maturity model evaluates existing concepts and offers an innovative framework for their implementation in the Indian MSME sector. The authors suggest evaluating the organisation over ten dimensions, each meticulously examined through seventy-nine elements. The purposive sampling analysis performed

to assess the overall maturity of manufacturing units within the MSME sector involved in the supply chain for OEMs in India reflects the maturity of the MSME units in multiple settings.

The survey analysis indicated a maturity level of two on a scale of one to five, signifying considerable deficiencies in the existing maturity degree, such as inadequate technological infrastructure and a lack of digital skills among the workforce. It is essential to know the importance of financial stability and the induction of new business leaders in MSMEs for a successful transition towards Industry 4.0. A notable area for improvement is the broad awareness of the human element, which requires urgent attention and collaboration between academia and industry to promote technology adoption. However, the data gathered and analysed related to the Indian context may

require revalidation for other geographies. As a universal framework, the established model is a comprehensive tool for assessing an organisation's current maturity level, pinpointing areas for focus, and facilitating periodic re-evaluation. In academics, the model offers a thorough catalogue of dimensions and attributes to evaluate during technological transitions, extending beyond adopting new technology for transformation.

REFERENCES

- ACTECH. (2013). *Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0: Final report, April*. Retrieved from http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report_Industrie_4.0_accessible.pdf
- Akdil, K. Y., Ustundag, A., & Cevikcan, E. (2018). Maturity and Readiness Model for Industry 4.0 Strategy. In A. Ustundag & E. Cevikcan (Eds.), *Industry 4.0: Managing the digital transformation* (pp. 61–94). Springer, Cham. https://doi.org/10.1007/978-3-319-57870-5_3
- Bahulikar, S., Chattopadhyay, A., & Hudnurkar, M. (2022). An Exploratory Study on Adoption of Industry 4.0 among SMEs with Specific Reference to OEM Supply Chain in India. *Manager: The British Journal of Administrative Management*, 58(153), 281–301.
- Bahulikar, S., Chattopadhyay, A., & Hudnurkar, M. (2023). Framework for Integrating Lean Thinking with Industry 4.0: Way Ahead for Entrepreneurs in Indian MSMEs. *The Journal of Entrepreneurship*, 32(2), 271–306. <https://doi.org/10.1177/09713557231184531>
- Basl, J., & Doucek, P. (2019). A Metamodel for Evaluating Enterprise Readiness in the Context of Industry 4.0. *Information*, 10(3), 89. <https://doi.org/10.3390/info10030089>
- Becker, J., Knackstedt, R., & Pöppelbuß, J. (2009). Developing Maturity Models for IT Management: A Procedure Model and its Application. *Business & Information Systems Engineering*, 1(3), 213–222. <https://doi.org/10.1007/s12599-009-0044-5>
- Buer, S. V., Strandhagen, J. O., & Chan, F. T. (2018). The Link Between Industry 4.0 and Lean Manufacturing: Mapping Current Research and Establishing A Research Agenda. *International Journal of Production Research*, 56(8), 2924–2940. <https://doi.org/10.1080/00207543.2018.1442945>
- Daultani, Y., Kumar, S., Vaidya, O. S., & Tiwari, M. K. (2015). A Supply Chain Network Equilibrium Model for Operational and Opportunism Risk Mitigation. *International Journal of Production Research*, 53(18), 5685–5715. <https://doi.org/10.1080/00207543.2015.1056325>
- De Vass, T., Shee, H., & Miah, S. (2021). IoT In Supply Chain Management: Opportunities and Challenges for Businesses in Early Industry 4.0 Context. *Operations and Supply Chain Management: An International Journal*, 14(2), 148–161. <https://doi.org/10.31387/oscm0450308>
- Francalanza, E., Borg, J., & Constantinescu, C. (2017). A Knowledge-Based Tool for Designing Cyber-Physical Production Systems. *Computers in Industry*, 84, 39–58. <https://doi.org/10.1016/j.compind.2016.12.006>
- Gerlitz, L. (2015). Design for Product and Service Innovation in Industry 4.0 and Emerging Smart Society. *Journal of Security & Sustainability Issues*, 5(2), 181–198. [https://doi.org/10.9770/jssi.2015.5.2\(6\)](https://doi.org/10.9770/jssi.2015.5.2(6))
- Ghobakhloo, M. (2018). The Future of Manufacturing Industry: A Strategic Roadmap Toward Industry 4.0. *Journal of Manufacturing Technology Management*, 29(6), 910–936. <https://doi.org/10.1108/JMTM-02-2018-0057>
- Gökalp, E., Şener, U., & Eren, P. E. (2017, October). Development of an Assessment Model for Industry 4.0: Industry 4.0-MM. In R. V. O'Connor *et al.* (Eds.), *International Conference on Software Process Improvement and Capability Determination* (pp. 128–142). Springer, Cham. https://doi.org/10.1007/978-3-319-67383-7_10
- Häberer, S., Lau, L., & Behrendt, F. (2017). Development of an Industrie 4.0 Maturity Index for Small and Medium-Sized Enterprises. In *7th IESM Conference, Saarbrücken, Germany*. Retrieved from http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report_Industrie_4.0_accessible.pdf
- Huddinah, E., & ER, M. (2019). Product Variety, Supply Chain Complexity and the Needs for Information Technology: A Framework Based on Literature Review. *Operations and Supply Chain Management: An International Journal*, 12(4), 245–255. <https://doi.org/10.31387/oscm0400230>
- Lasrado, L. A., Vatrapu, R., & Andersen, K. N. (2015). Maturity Models Development in IS Research: A Literature Review. *Association for Information Systems AIS Electronic Library (AISeL)*.
- Lichtblau, K., Stich, V., Bertenrath, R., Blum, M., Bleider, M., Millack, A., & Schröter, M. (2015). *IMPULS-Industrie 4.0-Readiness*. Impuls-Stiftung des VDMA, Aachen-Köln.
- Mendling, J., & Brocke, J. V. (2018). *Business Process Management Cases: Digital Innovation and Business Transformation in Practice*. Springer International Publishing AG. <https://doi.org/10.1007/978-3-319-58307-5>
- Mendling, J., Pentland, B. T., & Recker, J. (2020). Building A Complementary Agenda for Business Process Management and Digital Innovation. *European Journal of Information Systems*, 29(3), 208–219. <https://doi.org/10.1080/0960085X.2020.1755207>
- Mittal, S., Khan, M. A., Romero, D., & Wuest, T. (2018). A Critical Review of Smart Manufacturing & Industry 4.0 Maturity Models: Implications for Small and Medium-Sized Enterprises (SMEs). *Journal of Manufacturing Systems*, 49, 194–214. <https://doi.org/10.1016/j.jmsy.2018.10.005>
- Müller, J. M. (2019). Business Model Innovation in Small-And Medium-Sized Enterprises: Strategies for Industry 4.0 Providers and Users. *Journal of Manufacturing Technology Management*, 30(8), 1127–1142. <https://doi.org/10.1108/JMTM-01-2018-0008>
- Parkinson, B. (2014). *The Connected Enterprise Maturity Model*. Rockwell Automation.
- Paulk, M. C., Curtis, B., Chrissis, M. B., & Weber, C. V. (1993). Capability maturity model, version 1.1. *IEEE Software*, 10(4), 18–27. <https://doi.org/10.1109/52.219617>
- Pessl, E., Sorko, S. R., & Mayer, B. (2017). Roadmap Industry 4.0–Implementation Guideline for Enterprises. *International Journal of Science, Technology and Society*, 5(6), 193–202. <https://doi.org/10.11648/j.ijsts.20170506.15>
- Pfohl, H. C., Yahsi, B., & Kurnaz, T. (2017). Concept and Diffusion Factors of Industry 4.0 in the Supply Chain. In H.-J. Kreowski, B. Scholz-Reiter, & K.-D. Thoben (Eds.), *Dynamics in Logistics: Proceedings of the 5th International Conference LDIC, 2016 Bremen, Germany* (pp. 381–390). Springer International Publishing. https://doi.org/10.1007/978-3-319-45117-6_33
- Rojko, A. (2017). Industry 4.0 Concept: Background and Overview. *International Journal of Interactive Mobile Technologies*, 11(5), 77–90. <https://doi.org/10.3991/ijim.v11i5.7072>
- Schuh, G., Anderl, R., Gausemeier, J., ten Hompel, M., & Wahlster, W. (2017). *Industrie 4.0 Maturity Index: Managing the Digital Transformation of Companies*. Herbert Utz Verlag.

Schumacher, A., Erol, S., & Sihm, W. (2016). A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises. *Procedia CIRP*, 52, 161–166. <https://doi.org/10.1016/j.procir.2016.07.040>

Singapore Model. (2018). *Advanced Manufacturing*. Economic Development Board (EDB) Singapore. Retrieved January 17, 2023, from <https://www.edb.gov.sg/en/our-industries/advanced-manufacturing.html>

Sordan, J., Oprime, P., Pimenta, M., Chiabert, P., & Lombardi, F. (2022). Industry 4.0: A Bibliometric Analysis in the Perspective of Operations Management. *Operations and Supply Chain Management: An International Journal*, 15(1), 93–104. <https://doi.org/10.31387/oscm0490329>

Stefan, L., Thom, W., Dominik, L., Dieter, K., & Bernd, K. (2018). Concept for an Evolutionary Maturity-Based Industrie 4.0 Migration Model. *Procedia CIRP*, 72, 404–409. <https://doi.org/10.1016/j.procir.2018.03.104>

Ustundag, A., Cevikcan, E., Ervural, B. C., & Ervural, B. (2018). Overview of Cybersecurity in the Industry 4.0 Era. in a. Ustundag & E. Cevikcan (Eds.), *Industry 4.0: Managing the digital transformation* (pp. 267–284). Springer. https://doi.org/10.1007/978-3-319-57870-5_13

Ustundag, A., Cevikcan, E., Sarvari, P. A., Kaya, I., & Cebi, S. (2018). Technology Roadmap for Industry 4.0. In A. Ustundag & E. Cevikcan (Eds.), *Industry 4.0: Managing the digital transformation* (pp. 95–103). Springer. https://doi.org/10.1007/978-3-319-57870-5_5

Wan, J., Yin, B., Li, D., Celesti, A., Tao, F., & Hua, Q. (2018). An Ontology-Based Resource Reconfiguration Method for Manufacturing Cyber-Physical Systems. *IEEE/ASME Transactions on Mechatronics*, 23(6), 2537–2546. <https://doi.org/10.1109/TMECH.2018.2869817>

Yin, Y., Stecke, K. E., & Li, D. (2018). The Evolution of Production Systems from Industry 2.0 Through Industry 4.0. *International Journal of Production Research*, 56(1–2), 848–861. <https://doi.org/10.1080/00207543.2017.1403664>

ANNEXURE I: DETAILS OF DIMENSIONS AND ITS STAGES

Strategy Layer					
Dimension	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Business Strategy	Business Strategy does not exist	Business Strategy formulated, documented and shared internally	Business Strategy considers Industry 4.0 for future implementation	Industry 4.0 is an integral part of business strategy	Defined Industry 4.0 Strategic Actions are in implementation
Growth Plans	A growth Plan for the organisation does not exist	A growth Plan is formulated, documented, and shared internally	Growth Plan considers Industry 4.0 roadmap for future implementation	Industry 4.0 is an integral part of the Growth Plan	Industry 4.0-related Growth Plan actions are under implementation
Product Portfolio	Product Portfolio not defined	The product portfolio is defined and designed	Customer needs on product connectivity are understood	Products are being designed for connectivity	Products are connected
Manufacturing Processes	Conventional Manufacturing processes used in production	CNC machines used in production which are not connected	Sensors, IoT and real-time data capturing are used in the production	Machines are interoperable, and Process has predictive capabilities	Manufacturing processes are autonomous
Supply Chain Integration	A supply chain strategy is not developed.	A well-defined and communicated supply chain strategy exists in the organisation.	All roles and responsibilities are defined in the supply chain to avoid conflict, and data is shared based on need.	When improving supply chain performance, supply chain partners share risk, costs, and rewards, as data is shared across the value stream.	Processes, components and products are redesigned in collaboration with suppliers and customers.
Industry 4.0 Implementation Roadmap	The organisation lacks a clear understanding of Industry 4.0, and Roadmap does not exist.	The organisation understands the need, but the Implementation journey is unclear.	The organisation had clarity on implementation, but the roadmap was not defined.	The organisation had clarity on the definition of the implementation and implementation roadmap.	Implementation Roadmap under implementation based on organisation priority
Resource Allocation for Industry 4.0	Skill and technology gaps not known	Skill and technology gaps identified	Projects identified to close gaps	Budgets allocated for implementation	Implementation underway
Leadership acceptance for I4.0 across departments	Leadership unaware of the requirements	Awareness created at the leadership level	Gaps identified at the Department level	Plans identified at the department level	Plans are interconnected and prioritised at the organisational level
Management Conviction on I4.0 Application and Benefits	Management is not aware of I4.0	Management awareness and benefits are seen as an outcome of the I4.0 deployment	Management is involved in gap analysis as an outcome of real-time data	Management has formed teams and allocated resources for implementation	Management has built a mechanism to review outcomes of implementation and a support system for issue resolution
Technology Awareness of I4.0	The team is not aware of I4.0 technologies	Awareness exists for I4.0 technologies	Gaps and technologies are identified at the Department level	Related technologies are identified for cross-organisation implementation	Related technologies are under implementation across the organisation

ANNEXURE I – DETAILS OF DIMENSIONS AND ITS STAGES (CONT'D)

Strategy Layer					
Dimension	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Business Ecosystem for deployment of I4.0	The ecosystem is unaware of Industry 4.0 concepts	Awareness is created in the value stream about Industry 4.0	Common gaps are identified across value streams for the deployment of Industry 4.0 technologies	Industry 4.0 technologies are implemented in the value stream, Exchange of information and data happening in siloes	With technologies adopted across the value stream, a Mature ecosystem exists with a seamless exchange of data

Business Process Layer					
Dimension	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Business Processes	Business Processes are not defined	Business Processes are defined	Business Processes are data-driven	Business Processes are well-knitted within the organisation	Business Processes are well-knitted across the value stream
Design Processes	Design is done on a need-based	Design procedures are defined and documented	Design procedures are data-driven	Design procedures are transparent within the organisation	Design procedures are well integrated across the value stream
Product Development Processes	Product design is based on customer specifications	Product development is based on design capabilities	Product development is based on customer feedback, cost and quality gap of existing products	Product development is based on market trends	Product design is an outcome of innovation
Marketing Processes	A push-type marketing process is followed to meet customer delivery	A forecast-driven marketing process is followed to meet customer delivery	A forecast-driven process is followed, which is broken into weekly delivery buckets	Pull type and demand-driven marketing process	The marketing process is to deliver the unit requirements of the customer
Manufacturing Processes	Large batch sizes are planned for manufacturing.	Lean manufacturing is in place, and moderate volumes can be manufactured efficiently	Small Batches can be planned, and machines are capable of quick changeovers	Micro Batches can be planned, and machines are interoperable	Unit production can be planned based on real-time customer requirement

Customer Layer					
Dimension	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Customer Integration	Customer integration is not considered in business processes	The need for Customer integration is understood for effective decision-making	Customer integration happens in silos or a few departments of the organisation	Customer integration happens across the business processes	Customer is an integral part of the value stream
Requirement Mapping	Customers' requirements are not a part of the business plan	The need for mapping customer expectations is understood	Customers requirements are communicated to internal stakeholders periodically	Customer requirements flow to all the users on a factual, real-time basis and are fulfilled	Customer requirements can be predestined based on real-time data
Expectation Mapping	Customer touchpoints are not identified	Customer touchpoints are not identified	Customer expectations are captured periodically	Customer expectations flow to all the users on a real-time basis	Customer expectations can be predicted from smart products and simulation
Utilisation of Customer Data	The organisation does not identify the need to obtain customer data	The organisation identifies the need to obtain customer data	Customer data is captured on a real-time basis	Collected data is analysed and simulated to understand customer requirements.	Simulated data is capable of predicting the future trends and requirements of the customer
Connectivity with customer	Customer connectivity is on a need basis.	Customers are connected to the database, and information sharing happens periodically	Smart products communicate real-time information to the central database	Customers product usage and maintenance can be done remotely, and potential failures are communicated in advance	Customers are integrated across the value stream, and the requirements are fulfilled in a predictive manner
Customer Need Mapping	Product design does not consider customer needs	Customer need mapping is done periodically to design products	Customer needs are simulated to convert into an end product.	Customer needs are captured on a real-time basis for product design	Customer needs are seamlessly integrated across the value stream

ANNEXURE I – DETAILS OF DIMENSIONS AND ITS STAGES (CONT'D)

Product Layer					
Dimension	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Product Life Cycle Management	The life cycle of the product is not mapped	product life cycles well understood before designing a product	Products are designed with connectivity features	Products are designed to improve visibility	Products are designed to manage changes in related parts at ease
Product Feature Management	Customer touchpoints are not identified.	Customer touchpoints are periodically mapped to add features to the product	Product features are simulated to optimise the end product	Customer touch points are captured, and mass customisation of products	Customer needs are predicted, and feature units are customised to meet customer expectations
Product Variety Management	Organisation is tuned to produce in mass	Batch Production culture is developed	Lean tools are used to optimise batch sizes and quick changeovers	Real-time data is used to plan the production of low volumes in a flexible operation system	Predictive data is used to produce a unit batch size for any given product
Digitalisation of Products	Products do not meet the basic requirements of digitalisation	Products are designed to meet basic requirements	Products have basic data-capturing capabilities	Products have advanced data-capturing and simulation capabilities	Products are designed to deliver predictive capabilities and interoperability
Integration with Other products	Products are stand-alone and cannot be integrated with other products	Products can be integrated with other products	Special upgrades and technologies are required for product upgradation	Freely available technologies can be used for product upgradation	Products can be seamlessly integrated with other products

Production Layer					
Dimension	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Data Management in Production	No processing of Data	Storage of data for documentation	Analysing data for process monitoring	Evaluation for process planning / Control	Automatic process planning / Control
Machine Connectivity and communication	No communication	Field bus interfaces	Industrial Ethernet Interfaces	Machines have access to the internet	Web services (M2M software)
Networking across Plants	No networking of production with other business units	Information exchange via mail/telecommunication	Uniform data formats and rules for data exchange	Uniform Data formats and multiple divisions are linked to data servers	Inter-divisional, fully networked IT solutions on a common platform
ICT Infrastructure in production	Information exchange via mail/ telecommunication	Central data servers in production	Internet-based portals with data sharing	Automated information exchange (e.g. order tracking)	Suppliers/customers are fully integrated into the process of design
Man Machine Interfaces	No information exchange between the user and the machine	Use of local user interfaces	Centralised/decentralised production monitoring/control	Use of mobile user interfaces	Augmented and assisted reality
Flexibility to handle small batches	Rigid production systems and a small proportion of identical parts	Use of flexible production systems and identical parts	Flexible production systems and modular designs for the products	Component-driven, flexible production of modular products within the company	Component-driven, modular production in value-adding networks
Infrastructure Flexibility for managing variety	Production systems are rigid using SPM's and cannot accommodate any new parts	CNC machines used in production can accommodate changes; however, setup times are high	Tools like SMED are implemented for accommodating changes in the type of part produced; however, machines are not connected	Production infrastructure is connected and can accommodate changes in products with minor loss of productivity	Production infrastructure is interoperable and connected, which can accommodate changes in products without loss of productivity
Infrastructure Flexibility for managing variety	Production systems are rigid using SPM's and cannot accommodate any new parts	CNC machines used in production can accommodate changes; however, setup times are high	Tools like SMED are implemented for accommodating changes in the type of part produced; however, machines are not connected	Production infrastructure is connected and can accommodate changes in products with minor loss of productivity	Production infrastructure is interoperable and connected, which can accommodate changes in products without loss of productivity

ANNEXURE I – DETAILS OF DIMENSIONS AND ITS STAGES (CONT'D)

Production Layer					
Dimension	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Material flow in the organisation	Batch	Single Piece	Cellular	Just in time	Batch of one
Production Planning	Planning which is based on historical trends	Fixed Interval Production based on quarterly forecasts	Daily Plan on run time basis, which is converted to production schedules	A Pull Based on real-time planning, which can communicate to machines	Market linked Unit requirements which can be predicted through connected systems
Plant Capacity Mapping	Capacity is not mapped	Cycle times are mapped at part and machine level	OEE is calculated for optimising capacity utilisation	Capacity mapping is based on market demand on a real-time basis	Machines are interoperable
Plant Utilisation Mapping	Utilisation is not defined	Utilisation is defined and mapped manually	Utilisation is defined and mapped on a run-time basis	Machines are connected, and utilisation is known on a factual, real-time basis	Real-time plant utilisation is available, and gaps can be predicated
Plant Maintenance	Maintenance is on a breakdown basis.	Preventive maintenance tools are used	Autonomous maintenance tools are used with manual interfacing	Condition monitoring on real-time data is used to improve uptime	Predictive maintenance based on simulation of machine health is used to optimise machine uptime

Technology Use Layer					
Dimension	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Selection Of Technology	Current technology trends not known	Selection based on peer reviews	Selection based on customer push and meeting the computerisation requirements	Selection based on understanding of customer future needs and current gaps to improve visibility	Selection based on mapping the technology gaps and future needs of Autonomation
Life Cycle of Technology	The product life cycle of technology is not mapped	Technology trends and product life cycles are well understood before investment	Technology investments are done to improve connectivity	Technology investments are made based on improving the visibility of processes.	Technology investments are made based on predictive capabilities offered.
Autonomous Robots	Not aware	Robots used for loading and unloading operations	Robots are interfaced with machines	Robots are interfaced with Workmen	Robots automatically interface with each other
Simulation	Simulation not used	Aware of simulation tools	Simulation tools are used for the design	Simulation tools are used for business planning	Simulation tools are interfaced with customers
Horizontal and Vertical System Integration	Not Aware of Horizontal and vertical integration	Information interchange on a run-time basis within the departments	Digitally connected system with real-time data collection and sharing within the organisation on a need basis	Digitally connected system with real-time data analysis with predictive capabilities across internal value streams	Digitally connected system with real-time data analysis with predictive capabilities across internal and external value streams
The Industrial Internet of Things (IIoT)	IIoT awareness is missing in the organisation	Information technology to gather data	Information technology to get information and trends	Information and communication technology to understand trends	Information and communication technology to predict behaviour
Cyber security	Not aware	Secured internal network layer	Secured internal network layer and Service Layer	Secured internal network layer, Service Layer and Application layer	Preventive tools to maintain information security and integrity
The Cloud	Cloud solutions are not used	Cloud used for data storage	Cloud is used for analysing information from all value streams and predicting trends	Cloud used for sharing data across value streams for decision-making	Real-time usage of the cloud to share information across the horizontal and vertical value streams to predict changes

ANNEXURE I – DETAILS OF DIMENSIONS AND ITS STAGES (CONT'D)

Technology Use Layer					
Dimension	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Additive Manufacturing	Not aware of Additive manufacturing processes	Aware of additive manufacturing as a concept, its application, and usage	Third-party support for prototyping through additive manufacturing route	House Facility available for additive manufacturing of parts for research and development activities	Additive manufacturing is used as a standard manufacturing process to meet the customised needs of users
Real-Time Location System (RTLS)	Manual Monitoring of goods in transit and production. Raw material receipts and issues are tracked in a manual system.	The raw material is tagged with Bar codes for identification and tractability to monitor the quality of the product from a consumer perspective; data may not be used for internal analysis	Raw material traceability is being done from supplier to Plant using Barcoding. Data updating on a run-time basis at the end of the shift to monitor consumption and receipt	Raw material and WIP are being tracked using bar coding and RFID technologies. Data updating on the system happens on a real-time basis	Finished goods are tacked until delivery; raw material and WIP are tracked using bar coding and RFID technologies. Data updating on the system happens on a real-time basis
Radio Frequency Identification (RFID)					
Sensors and Actuators	Sensors and Actuators are not available on machines. Old generation machines which are operated on preventive and breakdown maintenance process	Machine parameters are stored in auto mode and retrieved periodically for analysis.	Data is captured in periodic intervals from machines. It is analysed to plot trends and derive actionable points	Sensors and actuators are used on a few machines to capture real-time data. The captured data on a factual real-time basis is used for making business decisions, which are corrective actions.	Real-time Data from all Machines and Equipment is captured in a digital thread directly from sensors and used for predictive analysis, such as condition monitoring, machine utilisation, tool consumption, etc.
Mobile Technologies	Not aware of Mobile technologies and not used for mapping data across the value stream	Mobile technologies are used on a few machines to capture data periodically. Data not used for reactive actions.	Mobile technologies capture data across vertical value streams on a run-time basis.	Mobile technologies capture data across vertical value streams on a factual, real-time basis.	Mobile technologies capture data across horizontal and vertical value streams in real-time.

Cyber Layer					
Dimension	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Importance of ICT in Organization	Importance of ICT not Known	ICT is Used in silos in a few departments for storage of data	ICT is used for computing data in a few departments	ICT is used for data management and decision-making within the organisation	ICT is effectively Used across the value stream for predictive analytics
Data Management within the organisation	Data is not captured and stored	Data is captured and stored as hard records	Data is captured and stored as soft records in repositories	Stored data is analysed on a factual, real-time basis for decision-making	Real-time data is used for predictive and autonomous decision-making
Data Management Outside organisation	External stakeholders' data is not captured	External stakeholders' data is captured on need-based	External stakeholders' data is captured through connected devices and sensors	External stakeholders' data is transparently visible on a real-time basis through connected products	External stakeholders' data is integrated with internal systems for autonomous decision-making
Data Management between Group companies	Group companies maintain independent data	The group company's data is stored on a command database for analysis	The group company's data is shared internally periodically to share best practices	The group company's data is shared internally on a real-time basis to map trends	The group company's data is integrated to make predictive decisions at the group level
Use of data for capacity mapping	Capacity mapping is done manually	Capacity mapping is done using ICT tools periodically	Real-time capacity analysis is done at the unit level to optimise utilisation using connected machines and sensor technology	Real-time information is shared within group companies for optimising capacities using connected components and sensors	Predictive information is shared within the companies for sharing of capacities and improving overall utilisation
Use of data for interoperability	Machines are used on a stand-alone basis	Machines are connected to ICT within the organisation	Real-time information is used for optimising productivity using connected components and sensors	Simulation tools for mapping cycle times are used to maximise productivity	Predictive tools are used for optimising productivity through interoperability

ANNEXURE I – DETAILS OF DIMENSIONS AND ITS STAGES (CONT'D)

Cyber Layer					
Dimension	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Platforms to share data	Data management and information sharing are missing	Data is captured, and Information is shared on a need basis	Data is captured on a real-time basis, and repositories are available to get sorted data	Simulation tools are used to give information to users based on the application usage	Predictive information is given to users based on historical trends
Use of Data Analytics	Data is not captured and stored	Data is captured but not analysed	Captured data is analysed and converted into information	Real-time information is shared with stakeholders for decision-making	Business analytics is performed and shared on a real-time basis with all stakeholders for decision-making
Mobile connectivity in operations	Machines cannot be connected	Machines can be connected	Wires connect machines with internal ICT	Machines are internally connected over Wi-Fi to make autonomous decisions	Machines are externally connected over mobile devices for autonomous decision-making
Security of data	Security firewalls do not exist	Security firewalls exist in novice form	Firewalls are at the equipment level	Firewalls are at the server level	Strong data security firewalls exist at each point of data collection and sharing
Knowledge repositories	Knowledge banks are not created	Knowledge banks are created	Knowledge banks are updated on a factual, real-time basis	Knowledge repositories are effectively shared within the organisation	Simulation tools are used for Knowledge sharing using captured data across the value stream

Supply Chain Layer					
Dimension	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Understanding Customer Requirements	Customer requirements are gathered from market trends	Customers communicate requirements based on their market forecasts	Customers communicate requirements every month	Customer requirements are mapped on a real-time basis	Predictive tools are available to map customer demand based on consumption
Customer Communication	The customer is not connected	Customer communication happens through emails/ phone	The customer has limited access to databases and communication with internal stakeholders	The customer is connected to the internal system, and data is shared on a real-time basis	Customer updates and requirements can directly flow to suppliers on a connected network in a controlled manner
Supplier Communication process	The supplier is not connected	Supplier communication happens through emails	The supplier has limited access to databases and communication with internal stakeholders.	The supplier is connected to the internal system, and data is shared in real-time.	Supplier updates and inputs can directly flow to customers on a connected network in a controlled manner.
Information sharing with suppliers	Information is shared need-based, and when asked	Information sharing is proactive	Information sharing is transparent	Information Sharing is on a real-time basis and vertically integrated	Information Sharing is on a real-time basis and horizontally integrated
Logistics Process	Information is provided with asked for	Human intervention is required to share information	Real-time information is shared with stakeholders transparently using geo-tagging and Sensors	Real-time information is shared with stakeholders with predictive capabilities	Real-time information is shared with stakeholders without human intervention

Communication Layer					
Dimension	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Vertical Data management	Data is not captured in manufacturing processes.	The need and importance of data is understood, and data capturing happens in isolation.	Data is captured across the organisation in real-time and stored in repositories for further processing and reactive decision-making as required.	Captured data is available transparently across the system and is used for simulating processes and decision-making.	Organisations have built capabilities to make autonomous decisions based on the available data and further predict machine behaviour.
Technologies for collecting and storing data	The importance of data is not felt in the organisation, and data is not collected	Manual record keeping, data is stored in computers as a repository at department levels	Data is collected using real-time sensors and other IIoT devices and stored in central repositories.	Collected data is available on the server or fog for local processing for usage by internal stakeholders	Collected data is available on the cloud and can be retrieved across the value stream by all the stakeholders

ANNEXURE I – DETAILS OF DIMENSIONS AND ITS STAGES (CONT'D)

Communication Layer					
Dimension	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Use of data for predictive quality	Quality-related data is captured manually and related to defects in component	Manual data collected in processes is analysed to understand the causes of reactive failures.	Real-time data was collected using digital tools to detect failures in the reactive processes.	Data collected using digital tools is used to take proactive actions to prevent failures.	Data collected using digital tools is used to build predictive capabilities of the processes and forecast failures
Use of data for predictive product reliability	Product reliability is an outcome of the designed factor of safety	Historical data of product failures is analysed to optimise the products	During new product development, real-time data from the product is used to improve the product's reliability	Smart devices in products can simulate the performance to prevent failures by stopping the device in advance	Smart devices in products can predict a balance life and communicate to the user the required actions to be initiated
Agility of internal manufacturing processes	Internal processes are rigid and cannot accommodate changes as built on SPM concepts	The process is built on general machines designed for large batch production with low flexibility to change.	Internal processes are built to produce small batches, with high change over time.	Internal processes are flexible and can accommodate changes to manage a high variety	Internal processes are interoperable and agile, and they can manage changes as external stakeholders require.
Flexibility of business process	Business processes are rigidly built over historical experience and are difficult to modify	Business processes have limited flexibility, and decision-making is concentrated on avoiding unforeseen impacts.	The organisation has understood the need for change and is building flexibility for effective decision-making.	Autonomy exists at all levels of the organisation, which is data-based decision-making in a defined framework.	Business processes adopt changes to the external environment quickly and have auto-correction and prevention mechanisms build
Decision-making layers	The organisation does not define a decision matrix; decisions are made need-based.	Centrally controlled decision-making process.	Multiple layers of decision-making with conflicting parameters	A structured decision hierarchy is in place, which is configured	The decision-making matrix is simplified, and autonomous decisions happen based on external and internal needs

People Layer					
Dimension	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Awareness of Industry 4.0	Individuals not aware of Industry 4.0 tools and technologies	Few members have Attended training sessions on Industry 4.0 tools and technologies	Cross-functional teams (CFT) are formed in organisations to build awareness and improve skills required for Industry 4.0 implementation	A dedicated team is formed for gap analysis and implementation	A dedicated team is using Industry 4.0 tools across the value stream
Need Identification	Usage and benefits of Industry 4.0 are not known to users	Users have attended training on the application and use of Industry 4.0 tools	Cross-functional teams (CFT) are used for the identification of needs and actions are planned	Common resources are used for the identification of needs, and actions are planned	Each Department has a dedicated resource for the identification of needs, and actions are underway for the implementation
Technology Awareness	Limited exposure to technologies used in the Industry 4.0 ecosystem and their impact on business decisions	Attended training and understood the impact of technology in specific domains of use	Awareness of the importance of real-time data management for effective decision making	Awareness of the usage of simulation tools and the need for building transparency in the value stream	Aware of the importance of Automation of Predictive analytics
Implementation Capabilities	The team is unaware of the I 4.0 implementation roadmap, with limited exposure to automation.	Training taken to identify gaps and I4.0 technologies for implementation	Using Industry 4.0 tools for Real-time data management	Implementing Industry 4.0 tools for simulation	Implementing Industry 4.0 tools for predictive analytics and Automation
Skill	Low exposure to technologies and tools used in the Industry 4.0 ecosystem	Teams have understood training needs and attended courses to bridge the skill gaps.	Developed skills to capture data from edge devices and sensors to capture digitalised data	Gained skill in mapping technologies and using simulation tools for business decision-making	Highly skilled in covert available technologies and tools for building predictive capabilities

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