Review of research issues and challenges of maturity models concerning industry 4.0

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Abstract: Over the years, technological developments and innovation in the area of manufacturing have evolved which is known as industry 4.0(I4.0), and has increased the consideration of all the researchers, enterprises and countries. Manufacturing enterprises are facing manifold challenges arising due to their internal and external situations. Similarly, choices have to be made among various available disruptive technologies, like IoT (Internet of Things), CPS (Cyber-Physical Systems) and cloud-based production. Thus, the need of the hour for manufacturing enterprise is to understand Industry4.0, subsequently, it is necessary to assist the manufacturing enterprises to assess their Industry 4.0 preparedness. German’s National Academy of Science and Engineering (acatech) has developed Industry 4.0 Maturity Assessment for establishing manufacturing enterprises Industry4.0 maturity and identifying areas where actions are required to realize higher maturity stage in implementation of Industry 4.0. In this article, a review of literature is made to comprehend the concept of Industry 4.0, and with focus on maturity models. Furthermore, the articles discuss the challenges, research gaps between the current status of manufacturing and I4.0. The findings of this review article may be the basis for understanding the challenges and designing a maturity model considering various dimensions of I4.0.

Keywords: Cyber-Physical System (CPS); Internet of Things (IoT); Maturity Model; Smart Manufacturing

1. INTRODUCTION

As we are living in a world of disruptive technology. Technological advances and innovation are now accelerating faster than ever before. As technology continues to evolve, it can impact all walks of our lives and society as a whole. Advancement in Information technology and computing skills leads to innovation of new products and services. Emerging technologies such as IoT, cloud computing, artificial intelligence and Big data. Integration of these technologies, machines were able to interact, analyze, exchange information, and coordinate among each other. It is a factory of the future, which is known as a “Smart Factory.” [4]

Enormous advances have happened in the area of ICT (Information and Communication Technology, it is crucial to integrate ICT into traditional strategies for successful implementation of I4.0, which leads to the implementation of the following features

Horizontal integration: It means Incorporation of varied Information technology systems, specially at a particular level of an enterprise, utilized in the various areas of the Production and business planning processes which involve an exchange material and knowledge within a
corporation and across different companies. **Digital integration of Engineering**: Integration of the digital world and real-world starting from the engineering process across the value chain and different companies. **Vertical integration**: Incorporation of various Information Technology systems at different levels of an enterprise to deliver a solution to the organization. [14] The technological developments enable the organization to do more with less. In other words, the organization can achieve more and do things faster by allocating resources more cost-effectively and efficiently. The reasons why industry 4.0 is gaining its importunacy are the benefits of it. It helps manufacturers becoming more flexible and making changes in the market easier. It can increase the innovation speed and it is a customer-centric approach, leading to faster design

1.1 Maturity
Maturity is a measuring the preparedness of industries aimed at continuous improvement in a specialized area, higher the maturity, the higher will be the chances that organization will lead to make improvements in quality and use of resources. Industry Preparedness Assessment (maturity) are assessment methods to analyze at what level the industry readiness of the conditions, attitudes, at various levels in a system. Assessment of maturity measurement will help the organization to know where they stand and how they need to go about achieving goals [2].
When it comes to Maturity Assessment of Industry 4.0, it will measure the current status of preparedness of industry for Digital transformation in terms of maturity level and prepare a Roadmap for the industry to achieve a higher level of maturity. Maturity Models will help an organization to reach higher maturity level in technologies through continuous improvement process. Different maturity models have reviewed through a Literature review and discussed in section 3 of this paper.

1.2 Current status of I4.0 in Universal Context
I4.0 evolved in 2011 as the technological strategy of the German government, which promotes the Digitalization.

In 2013 the German Academy of Science and Engineering (acatech) headed by Henning Hagerman presented the report of drive behind I4.0 at the Hannover Fair [3]. Globally, the Industry 4.0 market is predicted to grow by the year 2023. Countries like the China, USA, Japan and European nations like the United Kingdom, Ireland, Sweden and Austria are implementing Industry 4.0[11,19]. Adoption of industry 4.0 by the developed country like German, USA, Japan, Korea, threats to developing countries Like Russia Brazil, India, China, and South Africa nations to compete globally [3]. In the journey of adoption of Industry 4.0, BRICS nations will be facing many challenges.

Industry 4.0 demands that the workforce is expected posse’s skills such as Data analytics skills, Information Technology, etc. which does not match what currently industries are required and what worker possess as result of this there creates demand-supply mismatch [1].Currently, each nation of BRICS is working on the adoption of industry 4.0 china is gearing up in adoption by having more number Industry 4.0-related patent, industrial automation, additive manufacturing by companies, machine-to-machine communications and events in robotics. Compared to India, Brazil, Russia, South Africa. China has been leading by initiation Made in China2025. [3]

Brazil is coming up with progressive manufacturing policy. Russia is endorsing Industry 4.0 technology through its TechNet initiative. India is encouraging the manufacturing and use of Information &Communication Technologies by the launch of Digital India and Make in India programs [3,11] Adoption of Industry 4.0 in an international context requires a strategy for cooperation with worldwide associates to establish the collaborations.

A survey is conducted by German to identify the challenges of international cooperation and seek the expert’s opinion in various factors for industry 4.0 adaptation, the outcome of survey shows that many countries have similar understanding of industry 4.0, many experts of the countries believe
that they want to lead the way actively in shaping industry 4.0, some experts believe that there is risk of data security. Hence the results provided an important basis for international cooperation and established a common understanding of Industry 4.0. [3]

1.3 Industry 4.0 In Indian Context
Conferring to the Global Yearbook of Industrial Statistics 2016- presented by UNIDO, India has placed sixth in the world’s ten major manufacturing countries [12]. India stays far behind in the implementation of Industry 4.0 compared with international peers. During the last decades of the 20th century Industry 3.0 was a huge leap forward. However, in India, did not grab this opportunity that came because of shortage labor and lack of skills, the Indian government estimates only 5% Of whole labor force has experienced prescribed skills training (associated to 68% in the UK, 75% in Germany, 52% in the USA, 80% in Japan and 96% in South Korea) [1].

Substantial portion of the Indian industries remains within the Industry 2.0, phase with the utilization of technology a limited to use of computer system at the functional level on other, hand MSME has less access to information technology because of the high cost [11,20,21]. India is now all ready to directly into subsequence revolution, i.e., industry 4.0, where machines will equipped with the ability to communicate. The Indian Government set a target of accelerating the contribution of producing production to 25 percent of Gross Domestic Product (GDP) by 2025, from 16 percent currently. [19]

One of the important assets of India is nation’s expertise in the Information Technology sector. India is major suppliers of Information Technology in the world by having the world’s top Information Technology companies. India’s information technology skill, can now be leveraged locally to Catalyze Industry 4.0 implementation. Information Technology sector is expected to show an important role in the Industry 4.0 era. As a significance of this, Indian IT companies are now with the viewpoint to strengthen their I4.0 competences by R&D to grasp the opportunity. [12]

The government should act as a facilitator in extending support to the manufacturing sector by its reformative Programs which will create an ecosystem for encouraging to adopt a wide range of technologies into manufacturing to gain the competitive advantage and also government should be formulating a regulatory framework for adoption and introduce skill enhancement programs for bridging the skill gap.[22] In this direction Government of India taken several initiatives like the “Make in India” program in 2014[3,12], Digital India, smart city, and skill development program [1]: Make in India where the Government will partner industry in the economic growth of the country. The government will act as a facilitator and not the regulator. Digital India has been introduced by the Government of India is creating an ecosystem to increase Internet connectivity through the use of technology.

Skill India and start-up India programs are launched to ignite the young minds of India to acquire the required skills to take the country forward. India’s population is growing, and middle-class remains to be key demand drivers. India is the 12th major country to have skilled and semiskilled workers and a robust system of education, government is encouraging by policies like lower excise duties, automotive mission plans, the formation of National Electric Mobility Mission Plan 2020 and Faster Adoption and Manufacturing of Hybrid Land Electric Vehicle are beneficial for the sector. [20]

Income Tax deduction is given to the industries. A weighted deduction of 150% granted to the various bodies which includes Nations premier laboratory, Technical University’s these initiatives by the Government of India are help in adoption of I4.0.

The objectives of this paper is to review of literature on I4.0 and different models of maturity Assessment for checking the readiness of the industry 4.0 and identify the research gaps, future
directions. The section 2 of the paper presents the review literature related to Industry 4.0. Section 3 presents a literature review on maturity models’ section 4 deliberates the conclusion of the paper.

2. REVIEW OF INDUSTRY 4.0 RELATED WORK

Technological evolution has made a positive impact on manufacturing and it is termed as the fourth revolution of industrialization or Industry 4.0.

**Industry 1.0:** It is the first revolution of industries where water and steam-powered machineries were developed to help workers in the mass manufacture of goods.

**Industry 2.0:** in the early stages of the 20th century where the electricity is the source of power used for productions, and empowered businesses concentrate power sources on individual machines. This phase also saw the development of several managerial concepts. American mechanical engineer Frederick Taylor introduced approaches such as Division of labor, increased productivity, Optimization of work methods. Which helped in effective utilization of resources.

**Industry 3.0:** In 1970s with the use of technologies in electronics and information electronics and Information Technology to achieve further computerization of manufacturing.

**Industry 4.0:** The fourth, revolution is towards digitization of process. I4.0 which uses technology like the IoT and CPS where sensors is used to collect large amount data that can analyze and progress their work.

Industry 4.0, which will encompass the information and communication technology to make process automated and digitization. cloud computing has received attention by this new industrial revolution, has raised technological developments to be effective in the adoption of these advancements [14]. Table I shows the different technologies of industry4.0

| Technologies                       | Description                                                                 |
|-----------------------------------|-----------------------------------------------------------------------------|
| Cyber-Physical System             | CPSs are systems which connects the physical world through sensor and actuators to process the virtual information. |
| Artificial Intelligence           | The system which is able to performs the activities and requires human intelligence which will help in making decision. |
| Internet of Things                | Internet of things consists of system that consists of computing devices such as digital machines which are able to communicate between machines, which is going to reduce interaction between worker and |
| Big Data                          | "Big data" is one which will process the large volume of data which will analyze the information that treats ways to analyze, data and extract |
| Augmented Reality                 | Augmented reality is a communicating experience of a real-world situations by computer-processed perceptual information |
| Additive manufacturing            | It is making objects where joining materials to from 3D model data, by using subtractive methodologies. |
| Cloud Computing                   | Here the remote servers are used to accommodate on the Internet to store, manage, and process data, |
| Autonomous Robots                | Physical robots with greater autonomy which includes behavioral aspects. Autonomous robots are subsets of artificial intelligence. |
Industry 4.0, which has started in the year 2011 by Germany, is being implemented by several countries across the world [2]. I4.0 is a real-time driven by data intensive technology which will establish a robust connection between Cyber-Physical System and people, I4.0 implementation is to promote decision making by making use of high computing technology such as AI, Machine Learning and IoT. Smart manufacturing is a data-intensive application which makes use of Information technology, CPS, AI to make manufacturing more efficient and effective. Several numbers of applications were presented, such as CPS, Human-robot interaction on the shop floor. Smart manufacturing is still in the early stage. It can reach different heights in the near future [9]. Digitalization and intelligence are the need of the hour today. The main factors which are driving the process of adoption of Industry 4.0 are increased level of competition, Technological progress, and increased productivity.

The future factory is smart enough where manufacturing resources are being connected, exchange of information happens through IoT, which includes “things” and “objects” like RFID sensors which will send, store, process, and analysis information, [9], and therefore the system is intelligent to predict and maintain the machines which makes smart factories [4,15]. The business where complete connected through communication network between enterprises, supplier, logistic, and customer. Products will smart, which will have information and knowledge. Customer can order, change the order during the product is in the production stage.

Some of the researchers considering creating a structure or Framework [4] for development for Industry 4.0, in order to guide progress of Industry 4.0. The architecture will have 5C level the base level is Connection level and hierarchy continues till configuration level, connection level establishes the hardware connections like a sensor, network. Conversion level converts the data collected is analyzed, cyber level establishes control over the entire network, cognition and configuration level engages intelligence aspects, and these two levels have considered for the development of Industry 4.0, and also framework is designed to help the organization in implementing the framework focuses on following areas which require research interventions [16]

**Smart Design:** - Were design needs to be upgraded, CAD and CAM can interact with 3D printing, which integrated with the Cyber-physical system. **Smart Machine:** Robots and other machines need to be interconnected, and data of these entire can send in the cloud-based central system. **Smart Monitoring:** - Monitoring is the core function of manufacturing system deployment of sensors will help in monitoring real-time data. Smart Scheduling: - Advance model algorithms which draw the data captured by the sensor and advanced decision architecture are going to developed. Further research intervention required in data-driven intelligent manufacturing models and human-machine interactions [16].

As there's a robust need for the company-specific model to guide the industry in developing Industry 4.0 road map, the company can have these three-stage process models [7], which are “Envision, Enable and Enact.” Envision stage an organization acquaints with the overall thoughts of the I4.0 vision and aligns general I4.0 ideas with industry specific objectives and customer requirements. Main focus of this phase to reach an organization tailored Industry 4.0 vision. The “Enable” stage is converting I4.0 vision into a more concrete corporate model and to mature main policies to its fruitful implementation. “Enact” phase help in restoration policies into concrete projects. And finally, organization will come up with goals, specific teams, and managerial actions need to be properly defined. The Projects is analyzed and identify the resources needed, identification of potential risks, and expected to effect on the mission will getting to be realized. To ensure all the participants who are involved in I4.0 activities to possess standard framework and terminologies A model has been developed by the ZVEI (German Electrical and Electronic Manufacturers’ Association) called RAMI 4.0 (Reference Architecture Model Industry 4.0). [6] Contains of a 3-D frame of reference which defines all vital features of Industry 4.0.[5]
“Hierarchy Levels” axis these levels represent the various functions within the organization. Second axis called “Value Stream” axis, the horizontal axis represents the facilities and products, Life-cycle management for systems and products, utilized in industrial-process measurement, control, and automation. The third axis represents “Layers” where there are six layers on the vertical axis describe the machine into its properties [6]

Industries come across many challenges in adopting industry 4.0, industry needs high bandwidth to transfer data through communication channels [14], lack of skilled force and difficult to retain the worker under changing circumstances, lack of financial resources, data security [9], difficulty in coordination across organizational units, organizational resistance in accepting the change [17], standardization and No definite framework [8] are the major challenges faced by the industry especially Indian industries. Table 2 shows the assessment of today’s factory and Industry 4.0 factory

| Table 2 Contrast of today’s factory and 4.0 factory [13] |
|----------------------------------------------------------|
| **Data Source** | **Technology** | **Characteristics** | **Technology** | **Characteristics** |
|----------------|----------------|---------------------|----------------|---------------------|
| Element        | Sensors        | Exactness           | fault Detection| Aware Predict      |
| Machines       | Supervisor     | Productivity        | Condition-monitoring | Aware Predict |
| Manufacture Systems | Networked Systems | Productivity &OEE | Lean principles Work and waste | Self-configure maintain |
|                 |                |                     |                | Worry-Free Productivity |

3. REVIEW OF MATURITY MODELS

Industry 4.0 adoption demands a comprehensive maturity model that will guide the industry in transforming by identifying and analyzing the industry-specific dimensions and maturity levels [31].

Through the literature review, it observed that industry followed different methodologies in identifying dimension and maturity levels; the various Maturity models are discussed in the following sections. In arriving at a Maturity Assessment for measuring I4.0 readiness, the industry needs to identify the dimensions based on the characteristics of the industry, and each dimension will have maturity items that should be in chronological order in which the company is targeting these items. And each dimension maturity will assed in terms its readiness, which will be going to be measured levels 0 to 5 where Level 0 represents item is failed or having lack of attributes whereas Level 5 represents the item achieved the final state. Sample of dimensions and levels are shown below in the Table3 and Table 4, and Table 5 shows the different maturity models that are reviewed.

| Table 3. Dimensions of Maturity |
|--------------------------------|
| Characteristics | Maturity items implementation of strategy I 4.0 roadmap, accessible resources for realization, use of business frameworks. |
| Management       | The readiness of process leaders/ Management capabilities and Methods, central management for I4.0 |
| Customer         | Consumption of customer data, sales/services Costumer’s Digitalization and media capability |
| Products         | Individualization of products, Digitalization of products, Creation of mixing into other systems |
| Operation        | Decentralization Modeling of processes and simulation, Approach of Interdisciplinary, interdepartmental collaboration |
Table 4. Levels of Maturity

| Maturity Levels | Description |
|-----------------|-------------|
| L1              | No Consciousness about the digital process within the organization |
| L2              | Some understanding of the digital process and operative to generate data |
| L3              | Data is collected and moved for analysis and action |
| L4              | Data is analyze d, and implications are drawn |
| L5              | Decisions making are made separately, and the process established. |

3.1 Maturity Models

Table 5. Maturity Models

| Dimensions                      | Levels                  | Conclusion                                                                                                                                 |
|---------------------------------|-------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Smart Factory                   | L 0: Outsider           | Model as Six Dimension, eighteen maturity items, and six levels. the model also presents the action item for each of the level so that it       |
| Smart products                 | L1: Beginner            | will help the organization to take necessary strategy to overcome the obstacles and move forward in the process of transformation (For     |
| Smart operation                 | L2: Intermediate        | example if an organization is in level 0 so organization will strategies to go to next level 1 in the process of Transformation.)            |
| Data-driven                     | L3: Experienced         |                                                                                                                                            |
|                                 | L 4: Expert             |                                                                                                                                            |
|                                 | L5: Top performer       |                                                                                                                                            |

Schuh, Günther, et al. 2017.[2]

| Dimensions                      | Levels                  | Conclusion                                                                                                                                 |
|---------------------------------|-------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Information systems             | Level 1                 | The acatech Industry 4.0 Maturity Index provides businesses with guidance for Carrying where they stand out this revolution into learning, agile company. |
| Resources Organization Culture  | Computerization         | The index has four dimensions and six levels; it is a tailor-made maturity model for an individual organization.                                |
|                                 | Level2Connectivity      | Among the Levels, the first two will analyze the readiness in terms of Digitization and the rest four will be for analyzing readiness concerning Industry 4.0. |
|                                 | Level 3 Visibility Level |                                                                                                                                            |
|                                 | 4Transparency           |                                                                                                                                            |
|                                 | Level 5 Adaptability    |                                                                                                                                            |
|                                 | Level6 Predictive       |                                                                                                                                            |
|                                 | capacity                |                                                                                                                                            |

De Carolis, Anna. et al. 2017][24]

| Dimensions                      | Levels                  | Conclusion                                                                                                                                 |
|---------------------------------|-------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Design and Engineering          | L1 Initial              | The model has 5 Dimensions and 5 Levels; it helps the companies how they are ready for digital conversion. The levels have been based on the inspirational philosophies of the CMMI framework (Capability Maturity Model Integration) the scoring method for maturity valuation is used. |
| Production Management           | L2 Managed              |                                                                                                                                            |
| Quality Management              | L3 Defined              |                                                                                                                                            |
| Maintenance Management          | L4 Integrated and       |                                                                                                                                            |
| Logistics                       | Interoperable           |                                                                                                                                            |
|                                 | L5 Digital-Oriented     |                                                                                                                                            |

Weber, Christian, et al.” [25]

7
Data Storage and Compute Service-oriented Architecture. Information Integration Digital Twin Advanced Analytics

| Level | Description |
|-------|-------------|
| Level 0 | Non-existent IT Integration |
| Level 1 | Data and System Integration |
| Level 2 | Integration of Cross-Life-Cycle Data |
| Level 3 | Service-Orientations. |
| Level 4 | Digital Twin |
| Level 5 | Self-Optimizing |

The Model has established to assess the Maturity for Data-driven manufacturing consisting of five dimensions and six maturity levels, building upon each other. It helps firms to measure the maturity of their Information Technology architecture concerning data-driven engineering and Industry 4.0. It also outlines the steps essential to reach the next level of maturity.

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*Digital transformation: a roadmap for billion-dollar organizations. Capgemini consulting. Mit center for digital*[28]

Customer understanding
Customer touch points Top line growth Worker enablement Performance management Process digitization Digital globalization New digital businesses Digitally-modified businesses

| Level | Description |
|-------|-------------|
| Level 0 Beginners | |
| Level 1 Conservatives | |
| Level 2 Fashionistas | |
| Level 3 Digerati | |

Totally there are nine digital dimensions and four levels which will shape the transformation. They are the specific set of elements implemented by the organization. There are four Levels Beginners, Conservatives, and Fashionistas Digerati. Beginners. They are doing very little with advanced digital capabilities. Digital Fashionistas. They have implemented a large amount of digital stuff. Digital Conservatives: They understand the need for a strong unifying vision and governance and internal engagement, Digerati. These firms truly understand how to drive value from digital transformation.

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*Ganzarain, Jaione, and Nekane Errasti.*[30]

Envision Enable Enact

| Level | Description |
|-------|-------------|
| Level 0 Initial. | |
| Level 1 Managed. | |
| Level 2 Defined. | |
| Level 3 Transform. | |
| Level 4 Detailed | |

The model focuses on three stages in each stage is measured using five-level. Model is to guide and train companies identifying new opportunities for diversification in areas within Industry 4.0.

The model focuses on three aspects envision where the corporate defined an industry-specific vision and understands the necessity for Industry 4.0, and within the Enable stages the corporate identifies the technical capabilities of the corporate and Enact is that the phase of strategizing the Implementation.

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*Schumacher, Andreas, et al.*[26]

| Technology Products | Level 0 |
|---------------------|---------|
| Customers and Partners Value | Level 1 |
| Creation Processes Data & Information Corporate | Level 2 |

A model developed is used to guide industry which is involved in discrete manufacturing distinct products with a focus on in-house value conception There are eight dimensions and six levels, each dimension will have
4. RESEARCH ISSUES AND CHALLENGES

Industry 4.0 is in the initial stage of implementation, and it is gaining the attention of many countries because of its widespread benefits to gain competitive and productivity improvement. Globally many countries started adopting Industry 4.0, countries like Germany, Japan, and USA are leading the adoption [19], but there is a lack of framework, and lack of awareness in implementation, even though there are several reference architectures for industry 4.0, but they are not tested and evaluated with test cases. There is a need for scientific collaboration between the expert's nation and countries which are lagging. There are still insufficient research efforts in making use of Big data, IoT, Artificial intelligence, and in the area of data Analytics. In the Indian context, India is behind in adopting Industry 4.0 compared to its global peers, as the Indian majority of the industry still is in Industry 2.0. India needs a comprehensive framework for preparing a road map to take up this challenge. There exists a skill gap in adoption of Industry 4.0. India has a larger workforce base there is a need for the role of government intervention in filling this gap. When it comes to the maturity models, several models are developed to identify the maturity levels of industry readiness, on the other hand, an insufficient number of models that are validated with test cases.

5. CONCLUSIONS

The objective of this paper is to review the literature related to Industry 4.0 and maturity models to provide insights on the topics. When considering Industry 4.0, which is making use of cutting edge technologies to focus on establishing connectivity along the value chain through, smart manufacturing, smart product, smart machine, which are shaped by IoT, CPS (Cyber-Physical System), Big data and Artificial intelligence, has to go long way to have wider acceptance around the world. The Authors strongly believes that there is sufficient research has happened to give a theoretical background to understand Industry 4.0, but there are opportunities in the technological aspects of Industry 4.0.

There are many reference architectures for Industry 4.0 that have been developed with an emphasis on different layers of the organization, product life cycle, and different hierarchy levels giving a theoretical framework, but there is a need for testing of these models to help in the implementation of Industry 4.0.

The literature review shows that there are several challenges in the adoption of Industry 4.0, such as the skill gap as industry 4.0 demands the skilled workforce to handle data-driven technologies, standardization there is a lack of commonly accepted standards for industry 4.0. In SME’s lack of financial resources is the barrier for the implementation of technologies, computer networks, robots,
and Cyber-Physical Systems, data security is the major challenge in industry 4.0, where the industry has to protect from unauthorized access.

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