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Managing Digital Transformation: Maturity Model Development

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Abstract

Industry 4.0 (I4.0) is a new era of production emerging from the extensive digital networking and integration of resources, products, customers, suppliers, and other related parts along the production value chains. A well-designed transformation management system can help organizations build a comprehensive understanding of I4.0 and manage their efforts toward it. This research introduces a comprehensive readiness assessment model grounded in academic research on the existing models and practical realities, needs, and challenges in organizations. The developed model can be used as a reliable I4.0 management system to identify the current digitization level and develop strategies to overcome the barriers and capitalize on the drivers observed in their specific context.

Keywords: Industry 4.0, maturity model, digital transformation, readiness assessment

INTRODUCTION

The concept of Industry 4.0 (I4.0) was first presented in Germany in 2011 as a governmental initiative aiming to digitize manufacturing (Luthra et al., 2020). The I4.0 systems are based on well-defined design principles such as interoperability, virtualization, decentralization, real-time capability, service orientation, modularity, smart product, and corporate social responsibility. These principles can be enabled by various systems and technologies such as the Internet of Things (IoT), Cyber-Physical

Production Systems (CPPS), digital twins, additive manufacturing, real-time data collection, big data, and cloud system, among others (Gökalp et al., 2017; Schumacher et al., 2016).

The transition to I4.0 requires specific organizational, human, cultural, technical, financial, and governmental resources. If requirements are unmet, the company will experience increased transformation costs, decreased quality, and additional reworks. These constraints led researchers and business experts to develop tools, such as I4.0 Maturity Models (MMs), to assess companies' capabilities for a smooth transformation. MMs evaluate the capacity to integrate I4.0 solutions and reveal the strengths & bottlenecks. Companies employ I4.0 MMs to reduce transition costs, increase quality, and prevent reworks(Akdil et al., 2018). They are often represented as a self-assessment survey measuring a firm's readiness for the I4.0 transformation (Santos & Martinho, 2020). Additionally, some MMs provide detailed guidelines based on firm maturity levels (Colli et al., 2019). However, an extensive review of the relevant literature and existing models suggest that; i) many models cover the critical I4.0 design principles only partially; ii) they are mainly designed for companies of developed countries and insufficient to meet the characteristics and needs of emerging economies; iii) provide limited accessibility and understandability by SMEs; and iv) lack of an I4.0 roadmap or recommendation system for the company.

Thus, this study aims to introduce a new and comprehensive I4.0 maturity assessment model (COMMA 4.0) developed according to the design science approach (Hevner et al., 2004) and taking into account the significant gaps in the existing models.

MATERIAL AND METHOD

The design science research (DSR) approach (Hevner et al., 2004), a well-established methodology for developing frameworks, including I4.0 maturity models, was used to develop the proposed COMMA 4.0. The following fifteen most cited MMs (Table 1) were examined for their objectives, specialization, maturity stages, dimensions, items, corresponding design principles (DPs), assessment tools, recommendation system availability, and comprehensiveness.

Table 1. Reviewed maturity models

ID	Model
MM1	I4.0-MM (Gökalp et al., 2017)
MM2	I4.0 Maturity Model (Bibby & Dehe, 2018; Wagire et al., 2021)
MM3	I4.0 Maturity Assessment Framework (Bibby & Dehe, 2018)
MM4	I4.0 Maturity Model (Schumacher et al., 2016)
MM5	Acatech Industrie 4.0 Maturity Index (Schuh et al., 2017)
MM6	IMPULS—Industrie 4.0 Readiness (Lichtblau et al., 2015)
MM7	DREAMY - Digital Readiness Assessment Maturity Model (De Carolis et al., 2017)
MM8	A Categorical Framework of Manufacturing for I4.0 and Beyond (Qin et al., 2016)
MM9	Digital Operations Self-Assessment (Reinhard et al., 2016)
MM10	Maturity and Readiness Model for I4.0 Strategy (Akdil et al., 2018)
MM11	Three-Stage Maturity Model (Ganzarain & Errasti, 2016)
MM12	Digitalization Maturity Model for the Manufacturing Industry (Klötzer & Pflaum, 2017)
MM13	SIRI - Smart Industry Readiness Index (Lin et al., 2019)
MM14	Maturity Model for Data-Driven Manufacturing (M2DDM) (Weber et al., 2017)
MM15	SIMMI 4.0 – System Integration Maturity Model I4.0 (Leyh et al., 2016)

This detailed review stage revealed several gaps in the analyzed models. The first gap is that only a few models provide score-sensitive recommendations or a roadmap after the analysis. Others have been developed with a focus primarily on academic concerns rather than addressing the specific needs and challenges of firms seeking to improve their digitization performance. However, such road mapping is highly beneficial for organizations. Secondly, some MMs lack covering the fundamental I4.0 design principles. Especially corporate social responsibility, smart products, and service orientation are among the least covered design principles, which are essential components of the I4.0 transformation (Dikhanbayeva et al., 2020). DPs should be a focal point of maturity models and incorporated into the models from the design stage to correspond with the core concepts of Industry 4.0. Also, only a few models reflect differences between developed and developing economies.

The next step was the semi-structured interviews with I4.0 practitioners to capture their experience applying maturity models. Representatives of 15 companies were surveyed in 30-45 minutes online interviews. The respondents shared their degree of awareness about I4.0 MM, the extent of application of MMs, and barriers faced when applying MMs. The study also included investigations of COMMA 4.0 structure, its coverage of all I4.0 aspects and principles, and applicability in the targeted industries.

The assessment method is a set of procedures for data analysis outputting numerical performance scores for a company (Schumacher et al., 2016). For this, the weights of indicators were identified using the analytic hierarchy processes (Saaty, 1987). In addition to the assessment model, an advisory system was developed and embedded into COMMA 4.0. The advisory system uses the knowledge base created during the literature review and interview analysis to produce score-sensitive improvement suggestions and road mapping (Lukhmanov et al., 2022). Finally, COMMA 4.0 was introduced as an online assessment platform with a survey instrument, I4.0 library, automated analysis, and road mapping.

The developed COMMA 4.0 model was tested in 25 companies from different sectors. After completing the online survey and receiving a recommendation report, respondents provided feedback about the accuracy of the results, quality of recommendations, clarity of wording, and offered relevant suggestions. As a result, the authors improved the model accordingly.

RESULTS AND DISCUSSION

To propose the maturity dimensions and items of the new MM, the authors mapped the I4.0 maturity elements based on the reviewed literature, selected MMs, and interviews (Figure 1). In this stage, the authors iteratively improved the proposed model using anonymous feedback and the expert panel. Five field practitioners of I4.0 implementation were invited to address the research gap yet maintain all the advantages of existing MMs.

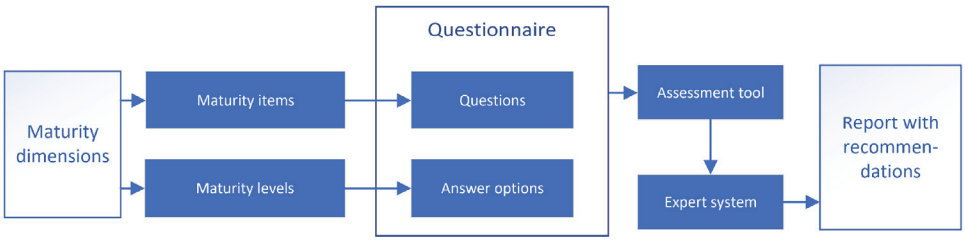

Figure 1. Structure of COMMA 4.0 maturity model

Maturity dimensions and Maturity levels

COMMA 4.0 consists of five maturity dimensions: strategy and organization, development of the workforce, smart factory, smart processes, and smart products and services. Each dimension contains several maturity items that reflect its most critical aspects and cover the main I4.0 design principles (Table 2).

Table 2. COMMA 4.0 components

Dimensions	Sub-dimensions	Covered I4.0 DPs
Strategy and Organization	I4.0 Strategy Implementation Business Performance Management (I4.0 related) Leadership support for I4.0 ICT organization ICT financial management Innovation and Change Management Collaboration with stakeholders for I4.0	Decentralization Modularity Corporate social responsibility
Workforce Development	WF Digital Competency WF Response to change Support for WF development	Corporate social responsibility Decentralization
Smart Factory	Automation degree of production system ICT Architecture Equipment upgradability M2M communication (data exchange) Digitization of enterprise data Observability of production Cloud Services Utilization Supply chain communication /integration	Interoperability Decentralization Modularity Real-time capability Virtualization Corporate social responsibility
Smart Processes	Standardization of business processes Use of business information systems (MIS/ERP) Data-driven decision-making Maintenance approach Quality management and Lean Systems	Interoperability Decentralization Modularity Real-time capability Virtualization Service orientation
Smart Products and Services	Digital Products and Digital Services Frequency of product/service upgrades Product customization degree Customer data utilization Sales channels used Revenue from data-driven services Intellectual property development Plans for digital features	Modularity Real-time capability Virtualization Corporate social responsibility Service orientation Smart products and services

Strategy and Organization is the first leading dimension in the proposed model. Despite the importance of technologies in the era of I4.0, strategic vision and correct organizational architecture, which are similar in importance, are often missed and underrated (Agca et al., 2017). To stay relevant, competitive, and profitable in the modern world, companies need to change, adapt or adjust the structures and processes of organizations. Leadership support in such cases and change management skills are essential in any transformational project (Lichtblau et al., 2015; Schuh et al., 2017).

The development of the workforce is the next main dimension. The organization's employees are the primary implementers of any changes; thus, the overall success of projects depends on their ability to cope (Schuh et al., 2017). Therefore, the workforce must be competent, continuously learning and

developing, possess the knowledge, and improve qualifications (Schumacher et al., 2016). It is the management's responsibility to create such an environment with flatter structures, less centralized decision-making, constant provision of pieces of training, and other actions.

Smart Factory represents the environment in which human intervention is minimal or only required in critical aspects. I4.0, in case of successful implementation, allows a high level of automation, where production processes can be carried out by the machines and equipment (Schumacher et al., 2016). Additionally, it will enable close inner and outer organizational collaborations in real time. One of the main tools used in Smart Factory is cyber-physical systems (CPS), with the help of which the physical world can be linked with the virtual (Gökalp et al., 2017).

Smart Processes are dedicated to maximizing the value of the technologies used in the plant. Only the integration of well-designed processes with technologies can bring the expected high results and enhance the efficiency of the whole factory. Implementation of I4.0 extends the opportunities and allows to change the focus from improving individual processes to improving the whole processes in operations, product lifecycle, and the supply chain (Akdil et al., 2018). This is possible through the integrated processes, real-time communication, and availability of the relevant data created by the intelligent facility (Agca et al., 2017).

Smart Products and Services are essential components of intelligent or smart factories (Leyh et al., 2016). Smart products are expected to collect and exchange data about location or its condition and others through equipped tools such as RFID, sensors, and other ICT elements (Lichtblau et al., 2015). In addition, the growing customer demand for more individualized products represents the need to establish a high level of digitalization and integration in all stages of the product cycle (Agca et al., 2017).

COMMA 4.0 maturity levels represent the readiness stage ranging from 1 (Entrant) to 5 (Expert).

- Level 1 (Entrant): represents the basic level of digitization, data processing, and communication. The traditional way of performing tasks also prevails in activities such as equipment repair, supply chain logistics, and horizontal and vertical integration.
- Level 2 (Beginner): digitalization projects are emerging, and the company leaders well understand the benefits of I4.0. Processes integration across the organization and automation level are performed at the primary level.
- Level 3 (Learner): transformational projects towards I4.0 are taking place at this level. ICT architecture of the organization is represented by the ICT department, helping to automate and improve the operational effectiveness of the processes. Data-driven decision-making approach is partially introduced.
- Level 4 (Integrator): projects with a specifically dedicated budget/investments to imply I4.0 tools are implemented. Processes within the organization are well-formulated and established, automation and digitalization levels and integration between horizontal and vertical levels are set up at a high level.
- Level 5 (Expert): I4.0 strategy is implemented across the organization. Real-time monitoring is available, the ICT department well supports and controls the processes, and it is actively integrated with all stages. Data-driven decision-making on an advanced level and continuous upgrade of products and services according to customer needs and demands is implemented.

I4.0 Readiness Scores and Recommendation System

Questions in the survey are designed as 5-scale Likert-type questions. The I4.0 readiness for each dimension is calculated as the weighted average of its sub-dimensions. As well, the overall I4.0 readiness for the whole data set is calculated as the average of all five dimensions. Furthermore, the algorithm highlights several aspects requiring special attention from the company. Identifying company bottlenecks and strengths is beneficial for resource allocation and SWOT analysis.

Additionally, COMMA 4.0 includes an automatic system that generates the report with score-sensitive recommendations. Each maturity item receives a set of recommendations regarding I4.0 readiness improvement. The suggestion's content depends on the company's current maturity state, such that the company receives only relevant advice. An automated, rule-based algorithm retrieves the recommendations from the knowledge base (Lukhmanov et al., 2022).

VALIDATION

One of the companies that participated in the case study has over 15 years of operating experience and is located in Atyrau, Kazakhstan. The firm maintains facilities in the petroleum, energy, and mining industries and is categorized as a large enterprise with over 250 employees. First, the chief operations manager filled out the questionnaire online. Next, the expert system calculated the maturity levels and generated a report of recommendations. Finally, two online meetings (45min each on average) took place to discuss in detail the results that the company received, the quality of recommendations provided, the format, and others.

As a result, the maturity assessment of the company in five dimensions with a weighted overall maturity level of 1.92 with the sub-dimension scores and relevant insights provided in Table 3.

Table 3. COMMA 4.0 Assessment results of the pilot company

Dimension / Score	**Insights**
Strategy and Organisation: 1.43	Three out of eight identified critical bottlenecks located hindering the development of the Strategy and Organization dimension are "lack of clear I4.0 transformation strategy", "lack of leadership support", and "underdeveloped ICT systems".
Development of the workforce: 3.33	The highest maturity level was received by this dimension. Therefore, the strengths of the company by maturity scores are revealed to be a "well-developed organizational innovative environment"; "well-established digital skills' development"; "high involvement of employees in changes
Smart Factory: 2.13	The second highest maturity score at this company was received by this dimension and includes both strength and bottleneck. Since the company operates in one of the most profitable sectors (petroleum, energy, and mining), the high result of the "upgradability of equipment" sub-dimension, which became a strength of the company could've been predicted. However, the bottleneck of the company was revealed to be a "lack of communication/integration with the supply chain".
Smart Processes: 1.6	The company received the lowest score in two sub-dimensions ("quality control" and "data-driven decision making"), which are the company's bottlenecks that deter I4.0 transformation. The "data-driven decision-making" sub-dimension depends on the extent to which the enterprise data is used for decision-making. At this point, the enterprise data is poorly used for decision-making.

Smart Products and Services: 1.56	The lowest results were received for this dimension. One of the bottlenecks of the company is the absence of intellectual property used in product development, it has scored the lowest score. Other sub-dimensions in which the company has the lowest score are "digital features in products", “digital features in services”, and “integration of digital sales channels”.

Along with a general result, an individual chart for each main dimension depicting all maturity items that the corresponding dimension consists of is also provided to the company. Further, based on the provided data, the company received a detailed analysis and recommendations for each sub-dimension. Concluding, the validation of COMMA 4.0 in a real-life environment is examined. The positive feedback received from the company, along with the results of the pilot testing. According to the comments, the recommendations report can greatly assist managers in improving business processes and the I4.0 level.

CONCLUSION

The proposed model aimed to address the gaps investigated in the existing models, such as the absence of full information availability, coverage of I4.0 design principles, applicability in emerging economies, and lack of recommendation systems, to provide companies with a plan for improvements. The developed model is domain-specific, with the scope to manufacturing industries/firms among the most valuable industries for developing countries. Moreover, it can be used in companies of different sizes, whether MNEs or SMEs. The target audience of the developed model could be experts, researchers, consultancy agencies, or providers of I4.0 technologies to use it as an assessment tool to diagnose the current conditions of the firms and to monitor the performance of the firms over time. Moreover, the model can be helpful for governmental organizations to get a view of the current state of manufacturing organizations, their needs, bottlenecks, and weak points, to reflect it in national support programs for businesses.

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