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Industry 4.0 readiness in manufacturing: Company Compass 2.0, a renewed framework and solution for Industry 4.0 maturity assessment

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Abstract

Industry 4.0 is prominent in the current research agenda, however, measuring the Industry 4.0 readiness and maturity in manufacturing is still challenging. There is no common definition for Industry 4.0 concept, and there are several Industry 4.0 readiness evaluation methods and maturity models in the literature. These models assess the Industry 4.0 maturity using different dimensions, frameworks, or maturity items. The most common dimensions from the literature are strategy, organization, technology, IT, smart factory, smart products, data utilization, and the human factor [1]. This paper provides Company Compass (CCMS) 2.0, a renewed Industry 4.0 conceptual framework and maturity assessment solution aiming to support Industry 4.0 progression. The suggested framework follows a holistic approach in Industry 4.0 maturity assessment by integrating the following dimensions: physical and virtual world, human, strategy and culture, products and services, value chain, and the broader environment. The main contributions of the suggested Industry 4.0 maturity assessment solution are its holistic view, its capability to highlight deficiencies, gaps of enterprises' Industry 4.0 readiness level, and providing guidelines for setting improvement goals and actions.

Keywords: Maturity; Industry 4.0; Digitalization; Industry 4.0 Maturity Model;

1. Introduction

Industry 4.0 and its readiness in manufacturing is a hot topic in the literature. It is a relatively new concept, but there are a growing number of academic papers deal with it [2][3][4][5][6]. Industry 4.0 determines the digital factory's key characteristics: all-automated manufacturing processes with human – autonomous machine collaboration in the center, eventually integrated into a supply chain. According to the Hungarian Industry 4.0 National Technology Platform approach:

"The term Industry 4.0 stands for the fourth industrial revolution based on cyber-physical systems, i.e., the formerly never seen integration of the physical and virtual worlds and represents a new level of organizing and controlling the entire value chain across product lifecycles. This cycle focuses on increasingly personalized customer wishes and extends from the concept to the order, development, production, and shipping of a product to the end customer and ultimately to its recycling, including all associated services. The foundation is the real-time availability of all relevant information through the integration of all objects in the value chain and the capacity to determine the optimal value flow at any time from the data. The interconnection of people, objects, and systems produce dynamic, real-time-optimized, self-organizing,

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cross-enterprise value-adding networks that can be optimized according to various criteria such as cost, availability, and resource consumption" [7].

Nowadays, numerous assessment models and methods are available regarding the readiness of Industry 4.0 implementation [4][5][6], we discuss them in Sect. 1.1. These maturity models use various maturity dimensions, like strategy, leadership, customer, product, operations, culture, and technology [4]. Mittal et al. [4] concludes that these maturity models have certain deficiencies, like they follow general approaches, e.g., there is no model that complies with all the specific requirements of manufacturing Small and medium-sized enterprises (SME). Nick et al. [1] developed an Industry 4.0 readiness model, called Company Compass (CCMS), which is based on pillars built on dimensions.

The predecessor of this maturity model is founded on three Pillars: Ecosystem, Value creation and Value. These Pillars are connected to Dimensions, that define individual aspects of industrial digitalization. Each Dimension is linked to Intervention points measured using an assessment questionnaire, describing the organization's digital readiness. The assessment questions maybe technology or business-focused in order to get broader information about the status of digitalization and Industry 4.0 readiness.

The most important output of the CCMS model is a list of prioritized intervention points that show the company the fields where it should make changes to reach a higher maturity level. For each dimension, there are eight predefined intervention points: to demonstrate the model approach and the structure of intervention points. As the different fields of action are in close relation to each other, the intervention points overlap and have common aspects in some cases.

Tests of CCMS models revealed that the companies' self-assessment depends heavily on the organizational hierarchy and the organizational approach. The additional problem is that the significant number of intervention points reduced the understandability and overlapping of the questions caused confusion. These difficulties led to the development of CCMS 2.0, the renewed CCMS model. The new goals are:

- targeted respondents have a managerial approach with industrial digitalization experiences.
- updated dimension set with renewed intervention points, which result more reliable feedback about the company Industry 4.0 maturity level for the strategy planning.

This paper provides a renewed version of CCMS Industry 4.0 maturity model [1] and is organized as follows: Section 1 provides the background of Industry 4.0, its definition, and the context. Section 1.1 discusses Industry 4.0 readiness models. Section 2. presents CCMS 2.0, the renewed Industry 4.0 maturity assessment model and solution. Section 3 summarizes the conclusion.

1.1. Industry 4.0 readiness models

"Readiness" and "maturity" are often used interchangeably in the literature. Weiner [8] defines readiness as "the state of being both psychologically and behaviorally prepared to take action". Readiness assessment usually aims identification of risks, opportunities, potential challenges, and barriers to success [9]. Becker et al. [10] argue that maturity models and readiness assessment models also aim an objective evaluation of a company's position, so we deal with both in the literature review. I4.0 maturity models provide a guideline and enabling frameworks as a benchmark enriched with improvement steps. Assessing I4.0 maturity levels reveal a status and position of a company in this roadmap with a protocol of progression through stages. It enables continuous improvements and support comparison of a company with the competitors.

There are several Industry 4.0 readiness evaluation methods and maturity models in the literature [4][5][6]. Mittal et al. [4] investigate 15 different maturity models in terms of the method they use, the focus, and the gaps found in them. These models assess the Industry 4.0 maturity in different dimensions that contain questions or maturity items. The organization or company is evaluated based on these elements by choosing an appropriate level of scale, which contains in general four to ten levels. In terms of these dimensions, the most common ones are the following: strategy and organization, technology, IT, smart factory, smart products, data utilization and employees. In some models, additional dimensions appear, too, for example security policies [11], performance [12] and customers [13]. The number of maturity items vary on a wide scale, e.g., the VDMA's online self-assessment questionnaire [14] contains altogether 18 items, but in another maturity model, the authors present a survey with 65 questions [13]. The VDMA's online self-assessment questionnaire [14] contains altogether 18 items separated into 6 dimensions, where the responding organization has to choose from options corresponding to 6 maturity levels (outsider, beginner, intermediate, experienced, expert, top performer) in case of each question. The dimensions are strategy & organization, staff, smart factory, smart operations, smart products, and data-driven services. The questionnaire was developed with the aim of self-assessment; thus, an organization can check its status regarding Industry 4.0 and take the first step towards digitization.

In [1] the authors stated that former maturity models are mainly technology-focused, and neglect other organizational dimensions, therefore, they present a model, which includes these aspects as well. They define indicators within 9 organizational dimensions, provide a model with 62 questions (maturity items) measured in 5 dimensions to assess the Industry 4.0 readiness of manufacturing enterprises – used in various cases in Austria. They also present a case study with an Austrian company. In [15], the authors introduce a 10-step Industry 4.0 realization model, which builds on their maturity model and Industry 4.0 strategic guidance.

One of the most known models from the previously listed ones is [16]. Basl et al. [17], Hizam-Hanafiah et al. [18] and Pacchini et al. [19] performed a systematic literature review of more than 20 maturity models.

Mittal et al. [4] and VDMA [20] draw attention to the SMEs importance from Industry 4.0 maturity aspects. SMEs are driving force of the industry and they are vulnerable from the implementation of Industry 4.0 in the first place. They conclude that those Industry 4.0 maturity models are valuable which comply with the SMEs' needs, which are customized for SMEs demands. They highlight the following lessons learned for progress:

- maturity models should take into consideration the differences between SMEs and other companies.
- there are gaps between non-integrated self-assessment readiness tools and maturity models.
- SMEs specific support as the next step after maturity and readiness is necessary.

The product itself determines the relevant areas of maturity models. Companies usually offer not only the products themselves, but the related services as well. Smart products because of their embedded digital characteristics are able to fulfill complex functions, and they provide specific services. Industry 4.0 maturity is not always interpretable and measurable for all actors of the ecosystem according to the traditional definition of Industry 4.0, however, they are valuable contributors. These contributors include Research Centers, universities; they are active partners of R&D&I processes, but there are some maturity areas, questions that are not meaningful (e.g., production scheduling) in their case. Experts Associations, Partner Organizations, Workers Representations are in a similar situation, they are not in the focus of the maturity models (they may not have industry-specific digital strategy neither).

Companies have distinctive features (e.g., size, domain, type, culture), so customized maturity models are preferable. Based on the review of Industry 4.0 maturity models we identified the following deficiencies and gaps:

- maturity models are mainly technology focused, they neglect managerial aspects and organizational dimensions.
- companies' size (SME, company) is not considered.
- type of production (e.g., process industry) is not dealt with.
- type of the company (service, production, etc.) is not examined.
- complexity and type of the product is not investigated.

2. CCMS 2.0 - The Industry 4.0 maturity assessment model and solution

This maturity assessment model is intended to correct the shortcomings of the previous one, described above. The advantages of this model are the management approach and the redefined intervention points. This not only takes a more comprehensive view on the various aspects, but also defines the desired state that organizations should aim to reach.

2.1. CCMS 2.0 Dimensions

The proposed CCMS 2.0 maturity assessment model combines the following dimensions: physical and virtual world, human, strategy and culture, products and services, value chain and the broader environment. It comprises of seven specific dimensions, that collectively describe the Industry 4.0 maturity of an organization. Within each dimension five Intervention points describe those critical areas, that influence Industry 4.0 maturity

Decision makers of the organization could develop specific actions around these intervention points to adjust Industry 4.0 maturity. The word adjust is used deliberately, as Industry 4.0 maturity of the organization may be higher than justified on certain dimensions, leading to imbalance, wasting valuable resources of the organization, and contradicting the general expectation of sustainability.

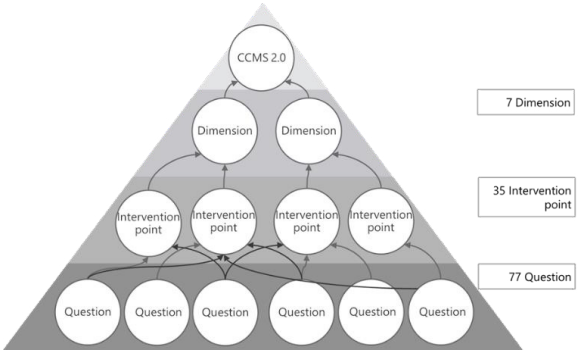

Fig 1. Structure of the CCMS 2.0 model

Maturity is determined using an assessment instrument that includes 77 questions, see Fig. 1. Each question is assigned to a primary Intervention point and optionally assigned to a secondary one, enabling to limit the number of questions but carry out the analysis on a broad basis.

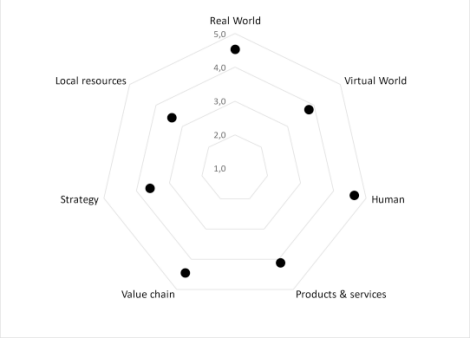

Fig 2. Maturity at dimension level

The questions within the Intervention points are weighted, to ensure that the relative importance of the areas is in line with the findings of our literature review. No weights are applied for the Intervention points within the Dimensions as they are equally important.

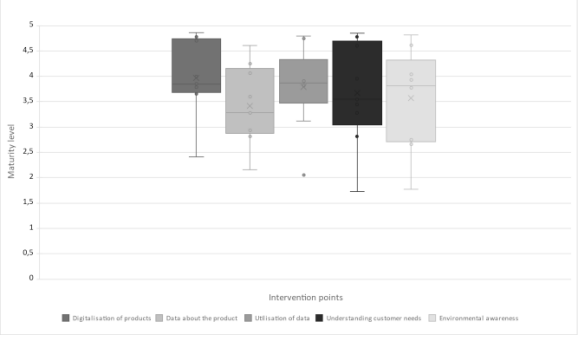

Fig 3. Intervention points results presented in Box plot

The results of the model are also visualized at the level of dimensions and intervention points. In Fig. 2 and Fig. 3, we present the results of the completions of mixed, 2 industrial and 7 scientific experts. When completing the questionnaire in a pilot way, they were tasked with completing them in an ideal state. While we concentrate the results in only one sense at the dimension level, we present the entire range in more detail within a dimension, i.e., in terms of intervention levels, using a box plot. The results of the expert fill-ins can also be considered a kind of baseline.

Table 1. Dimensions and their definitions

Dimension	Dimension definitions
Physical world	The plant and equipment of the supply chain (manufacturing and logistics) that is fitted with cyber-physical systems integrated into the broader ecosystem vertically and horizontally.
Virtual world	The "digital twin" of the Physical world, used to automate, remote control, optimize, and simulate the operation of the plant and equipment of the supply chain. Data is the connection between the physical and the virtual world.
Human	The People are able to exploit the possibilities provided by the virtual world, to integrate it to the ecosystem and to improve competitiveness. They require analytical, modeling and simulation skills, inter alia.
Products and services	The products and services hold such digital content, that add value to the participants of the ecosystem including the customers and enables their integration to the ecosystem.
Value chain	The operation is integrated to the broader supply chain, through sharing data, joint systems, and creating a virtual world that stretches beyond the boundaries of the business.
Environment	The local resources surrounding the business form an ecosystem, that collectively contribute to business competitiveness and sustainability. They comprise among others the regulatory framework, the presence of academic and research institutions, and the supply networks.
Strategy and culture	Business strategy, approach and culture acknowledge that competitiveness relies on exploiting the opportunities of the virtual world and its integration to the broader ecosystem. Therefore organizational, capability and process development efforts are all aimed towards this goal.

The following section will describe the Intervention Points in detail, which are used to measure Industry 4.0 readiness of the business. Each Dimension has five Intervention Points describing the desired end state, helping the business to set directions for developments.

2.2. Intervention points

Physical world

These Intervention Points would test the capabilities of the plant and equipment of the supply chain, how they are fitted with cyber-physical systems that enables their automated operation and their integration to the broader ecosystem vertically and horizontally.

- **Autonomous operation**: the production equipment and robots are capable for autonomous operation (they perform the assigned task and/or feedback on their availability)
- **Upgradeability** of production equipment and infrastructure: the production equipment can be upgraded to new functions and capabilities.
- **Data acquisition**: equipment is fitted with sensors that monitor their operation and environment, collecting and transferring data about their status, operation and the processes performed.
- **Information exchange and communication**: IT infrastructure, network and software environment support the data acquisition. Equipment is fitted with standardized, secure digital communication devices.
- **State of the art technologies**: the business applies the latest hardware, software and manufacturing technologies to support its production and logistics processes.

Virtual world

These Intervention Points would explore how well the digital twin is developed, how data is collected and exploited for the automated execution and the ongoing improvement and integration of supply chain processes.

- **Data acquisition and storage**: data is collected from equipment operation, internal business processes and from the participants of the ecosystem in such a way, that enables automated data processing.
- **Data exploitation**: The data that is collected during production is utilized for process improvement, optimization, and decision support.
- **Digital twins** of the production and logistics process are created with the aim of its connected, autonomous application for the participants of the ecosystem.
- **Automated, intelligent processes**: Business processes are automated in such a way, that are able to adapt to the changes of their environment. Employees are predominantly engaged in process validation, improvement, and development.
- **Security awareness of the company**: information systems meet the security requirements that are defined according to business needs. (confidentiality, integrity, availability, compliance with regulatory requirements)

Human

The intervention points related to the Human dimension of Industry 4.0 are concerned with the role of people in the business, their digital capabilities and ability to develop those, as well as the new ways of working like remote work and mobility.

- **Role of people in manufacturing:** is primarily focused on coordinating, analyzing and improving processes, as opposed to of operating and attending them.
- **Openness for new technologies**: Employees have the necessary skills to employ digital technologies and are open to learn and apply new ones.
- **Internal training for digital technologies**: the company's strategy provides resources and manages actively the employees' development for the challenges of the new, digital world.
- **Digital workplace**: mobility, remote work and communication is part of the company's strategy, providing all the tools and infrastructure.

- **Safe working environment**: Safety is a primary concern for the company, providing all the resources necessary.

Products and services

These intervention points examine the digitalization status of products and services, how much digital content they carry and how this digital content is used for process improvement, after sales service or understanding customer needs for product upgrade and development.

- **Digitalization of products**: Products and services contain digital content that either provides additional value to customers/participants of the ecosystem or enables their integration into the ecosystem.
- **Data about the product**: Data is collected about the products, their operation, and potential defects, during the entire life cycle, in the context of their usage.
- **Utilization of data**: Data that is collected during the life cycle of the product is utilized for the improvement of the production process and/or for automated after sales service and troubleshooting.
- **Understanding customer needs**: Product development is using state of the art digital technologies, utilizes the data that is collected during the product's life cycle and enables the remote, digital upgrade of the product.
- **Environmental awareness**: Sustainability and environmental impact of the product is primary concern during production and product development.

Value chain

These intervention points probe the integration of the value chain, the use of digital data and communication for the automated execution of processes, and position and the interdependence of the company in the value chain.

- **Digital partner connections**: digital readiness of partners enables the modeling and the autonomous connection of manufacturing and logistics processes with them in the supply chain. The automated and autonomous processes extend beyond the company's boundaries, they are aimed at synchronizing the activities and executing them autonomously.
- **Strong partnerships**: strong integration, trust and interdependence characterize the company's partnerships with the participants of the value chain. They specialize to supply complementary services.
- **Research and innovation network**: the company is keen to participate in joint research, development, and innovation activities with the members of the value chain and open for knowledge sharing.
- **Prominent role in the value chain**: the company delivers added value by holding a prominent role in the value chain, being an expert and leading the development of its field.
- **Sustainable supply chain**: reducing the environmental impact of the supply chain is the focus of developing and implementing the strategy.

Environment

It is acknowledged that the environment, the company operates contributes to competitiveness and sustainability, therefore these intervention points analyze if local resources like the infrastructure, the regulatory environment, financial resources and the labor market could support the business.

- **Infrastructure**: the environment where the company operates has the necessary infrastructure that is required for competitiveness in the digital era.
- **Regulatory environment**: stable legislative and regulatory environment supports predictable operation and competitiveness.
- **Financial resources**: stable financial environment, accessible resources supports developing the business and the implementation of projects.
- **Labor-force**: there is sufficient, well skilled manpower available in the neighborhood to support the uninterrupted operation and the development of the company.
- **Cooperation opportunities**: there are partners in the neighborhood that are willing and capable to build a competitive supply chain.

Strategy and culture

Finally, the intervention points related to strategy and culture would investigate the company's resolute efforts to develop, implement and monitor the implementation of its Industry 4.0 strategy and create a conducive culture.

- **HR strategy**: the company recognizes the HR challenges of digitalization and incorporates them in its strategies.
- **Industry 4.0 strategy**: the company has an Industry 4.0 strategy with specific development areas, provides resources to monitor key trends and digital developments.
- **Strategy implementation**: the company provides (internal and external) resources for the implementation of its Industry 4.0 strategy and monitoring its success.
- **Research, Development, and Innovation**: the company recognizes, that Research and Development is key in developing the operation and new products, services.
- **Company culture**: is agile, open for innovation, supports experimentation and cooperation with the participants of the ecosystem including competitors.

2.3. CCMS 2.0 contributions

The definitions of these Intervention points describe an Industry 4.0 ready organization that exploits connected and autonomous equipment opportunities, resulting in improved performance, responsiveness, and competitiveness. The role of people in this organization is to validate, improve and develop processes, robots and autonomous, automated plant and equipment is able to carry out the operation without the need of operator supervision. Data plays a unique role in this environment: it connects the physical and the virtual world, carries valuable information about the entire life cycle of the product, and acts as a link between the organization and the ecosystem. Data is used for continuous process improvement as well for developing new products. Acquiring the latest technology is not sufficient on its own to achieve Industry 4.0 readiness. Strategy and company culture should support the implementation of projects and provide a conducive environment for experimentation, collaboration, and knowledge sharing.

This CCMS 2.0 Industry 4.0 readiness framework provides a comprehensive approach to describe the organization's status of digitalization and to define the future. Several studies highlight [13] [21], that Industry 4.0 projects are hindered by the lack of complex approach, obscure benefits and inaccurate self-assessment. We believe that our CCMS 2.0 framework overcome these common mistakes by taking an interdisciplinary approach, providing an accurate and transparent view on the status of Industry 4.0 and defining future directions and desired states. Having an accurate diagnosis about the state of digitalization would help developing the Industry 4.0 strategy, that could be translated to specific action items, innovation projects and interventions using the Intervention points of the model. This should support competitiveness and contribute to improved performance. Organization maturity should be re-assessed at regular intervals to fine-tune strategy, develop new projects, and support ongoing improvements.

3. Conclusion

This paper presents a renewed CCMS model, an Industry 4.0 conceptual framework and solution aiming the Industry 4.0 maturity assessment. The suggested framework, CCMS 2.0 follows a holistic approach in Industry 4.0 maturity assessment by integrating the following dimensions: physical and virtual world, human, strategy and culture, products and services, value chain and the broader environment. The main contributions of the suggested Industry 4.0 maturity assessment solution are the holistic view, the managerial approach, the capability for highlighting the deficiencies, gaps of enterprises' Industry 4.0 readiness level and providing guidelines for the improvement.

Tests of CCMS models revealed some gaps and problems, like the significant number of intervention points reduced the understandability and overlapping of the questions caused in some cases confusion. These difficulties led to the need for a renewed CCMS model, with new goals. CCMS 2.0, the renewed model targets respondents with managerial approach and industrial digitalization experiences. We updated dimension set with renewed intervention points, which result more reliable feedback about the company Industry 4.0 maturity level for the strategy planning and governance.

This model provides effective solution for Industry 4.0 maturity level assessment for manufacturing companies and logistics partners of corporate sector companies and enterprises. Future work includes SMEs customization and develop a model for service industry.

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