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A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises

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Abstract

Manufacturing enterprises are currently facing substantial challenges with regard to disruptive concepts such as the Internet of Things, Cyber Physical Systems or Cloud-based Manufacturing – also referred to as Industry 4.0. Subsequently, increasing complexity on all firm levels creates uncertainty about respective organizational and technological capabilities and adequate strategies to develop them. In this paper we propose an empirically grounded novel model and its implementation to assess the Industry 4.0 maturity of industrial enterprises in the domain of discrete manufacturing. Our main goal was to extend the dominating technology focus of recently developed models by including organizational aspects. Overall we defined 9 dimensions and assigned 62 items to them for assessing Industry 4.0 maturity. The dimensions "Products", "Customers", "Operations" and "Technology" have been created to assess the basic enablers. Additionally, the dimensions "Strategy", "Leadership", Governance, "Culture" and "People" allow for including organizational aspects into the assessment. Afterwards, the model has been transformed into a practical tool and tested in several companies whereby one case is presented in the paper. First validations of the model's structure and content show that the model is transparent and easy to use and proved its applicability in real production environments.

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1. Introduction

Manufacturing companies around the world are facing substantial challenges due to recent environmental, societal, economic and technological developments. To meet these challenges manufacturing companies of the future will need capabilities for managing their whole value-chain in an agile and responsive manner. Companies will need virtual and physical structures that allow for close cooperation and rapid adaption along the whole lifecycle from innovation to production and distribution [1].

Current state-of-the-art in production technology can be described as mainly driven by increasing efficiency regarding manufacturing processes. However, this focus of advances in manufacturing efficiency takes place on the individual firm rather than on the whole supply chain. Advances can also be seen on the organizational-economic level, e.g. Lean Management, on the manufacturing technology level, e.g. Laser technology, additive manufacturing, robotics [2] on the material level, e.g. semi-conductors, nano materials, carbon fibres, thin-films, biomaterials [3], on the information technology level, e.g. RFID, embedded systems. All these advances have led to significant but isolated gains in process efficiency and product quality.

Hence, for decades to come both academics and practitioners envision significant efficiency gains mainly through consequent digital integration and intelligentization [4] of manufacturing processes [5]. Accordingly, integration will need to take place on horizontal level (across all participants in the entire value-chain) and on vertical level (across all layers of automation). Fully integrated and networked factories, machines and products then will be able

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to act in an intelligent and partly autonomous way that requires minimal manual interventions [6].

Recent concepts such as the Internet of Things, Industrial Internet, Cloud-based Manufacturing [7] and Smart Manufacturing address these requirements in part and are commonly subsumed by the visionary concept of a Fourth Industrial Revolution (Industry 4.0) [8]. Industry 4.0 refers to recent technological advances where the internet and supporting technologies (e.g. embedded systems) serve as a backbone to integrate physical objects, human actors, intelligent machines, production lines and processes across organizational boundaries to form a new kind of intelligent, networked and agile value chain.

It is obvious that such a far reaching vision will lead to an increased complexity of manufacturing processes on the micro and macro level [9]. Especially small- and medium sized manufacturing companies are uncertain about the financial effort required for the acquisition of such new technology and the overall impact on their business model.

Experiences from several strategic orientation workshops [10] with various companies have shown that companies have serious problems to grasp the overall idea of Industry 4.0 and particular concepts hereof. On the one hand, they are not able to relate it to their specific domain and their particular business strategy. On the other hand, they experience problems in determining their state-of-development with regard to the Industry 4.0 vision and therefore fail to identify concrete fields of action, programs and projects. To overcome growing uncertainty and dissatisfaction in manufacturing companies regarding the idea of Industry 4.0, new methods and tools are needed to provide guidance and support to align business strategies and operations.

In this paper we will describe the results of a recent research effort where we developed a maturity model and a related tool to systematically assess manufacturing companies' state-of-development in relation to the Industry 4.0 vision. Our maturity model serves both a scientific and a practical purpose. The scientific purpose aims at gaining solid data about the current state of manufacturing companies and their Industry 4.0 strategies to extract potential success factors. The practical purpose of this work aims at enabling a company to rigorously evaluate their own Industry 4.0 maturity and reflect the fitness of current strategies.

The paper is structured as follows. In section 2 we discuss existing maturity or readiness models in the relating domain and derive our research contribution. Followed by section 3 where our concepts of organizational maturity are described as well as the framework to develop the Industry 4.0 Maturity Model. In Section 4 we introduce the resulting model and details about the procedure to assess maturity. In section 5 we outline first findings from a preliminary evaluation by discussing the results of a case study conducted in a manufacturing company. Finally, in section 6 we conclude about main findings, limitations of the model and define future research.

2. Existing maturity and readiness models in relevant domains

In general, the term "maturity" refers to a "state of being complete, perfect, or ready" [11] and implies some progress in the development of a system. Accordingly, maturing systems (e.g. biological, organizational or technological) increase their capabilities over time regarding the achievement of some desirable future state. Maturity can be captured qualitatively or quantitatively in a discrete or continuous manner [12].

Maturity models are commonly used as an instrument to conceptualize and measure maturity of an organization or a process regarding some specific target state. Labelled synonymously are readiness models with the goal to capture the starting-point and allow for initializing the development process. We understand the difference between readiness and maturity in the matter that readiness assessment takes place before engaging in the maturing process whereas maturity assessment aims for capturing the as-it-is state whilst the maturing process. In the production domain recent readiness and maturity models have been proposed for example in energy and utility management [13], in eco design manufacturing [14] or lean manufacturing [15]. With regard to the domain of Industry 4.0 the following models and tools for assessing readiness or maturity have been published:

Table 1. Existing Industry 4.0 readiness and maturity models.

Model Name	Institution/ Source	Assessment Approach
IMPULS – Industrie 4.0 Readiness (2015)	VDMA, RWTH Aachen, IW Consult 16]	Assessment in 6 dimension including 18 items to indicate readiness in 5 levels; barriers for progressing to the next stage are defined as well as advice how to overcome them
Empowered and Implementation Strategy for Industry 4.0 (2016)	Lanza et al. [17]	Assessment of Industry 4.0 maturity as a quick check and part of a process model for realization; gap-analyses and toolbox for overcoming maturity-barriers are intended; no details about items and development process offered
Industry 4.0 / Digital Operations Self Assessment (2016)	Pricewater-houseCoopers [18]	Online-self assessment in 6 dimensions; focus on digital maturity in 4 levels; application as consulting tool as fee for assessment is required in 3 of the 6 dimensions; no details about items and development process offered
The Connected Enterprise Maturity Model (2014)	Rockwell Automation [19]	Maturity model as part of a five-stage approach to realize Industry 4.0; technology focused assessment in 4 dimensions; no details about items and development process offered (white paper)