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TOWARDS A MATURITY MODELING APPROACH FOR THE IMPLEMENTATION OF INDUSTRIAL INTERNET

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Abstract

This Research-in-Progress paper facilitates the design and provides guidelines for the development of a maturity model to achieve a coordinated, systematic and stepwise adoption of industrial internet, thus enabling the industrial internet to be used to its full potential in manufacturing enterprises. Using analogous maturity models from the fields of supply chain management and product lifecycle maturity among others, this paper explains why a maturity model approach would facilitate the step-by-step implementation of industrial internet. The paper goes on to provide systematic design guidelines for industrial internet maturity model for mass production manufacturing industries which use heavy equipment. The detailed research design presented here uses ADR methodology to enable the construction of the ensemble artefact. The industrial internet maturity model will be tested, developed and validated using the experience-based feedback from industrial practitioners. This will enable the industry to plan a roadmap to assess the current situation and define the direction for the future development of industrial internet related activities and business models for industry.

Keywords: Industrial Internet, Maturity Model, Design Guidelines

1 Introduction

Industrial internet is a phenomenon that brings together the digital world with the physical world of machines. It combines industrial systems with the power of advanced computing, low-cost sensing, analytics and innovative connectivity using the internet (Agarwal & Brem 2015). The concept of industrial internet involves collecting large amounts of data by embedding sensors and advanced instrumentation in machines, which is analyzed to offer real-time intelligence.

General Electric (GE) coined the term "*Industrial Internet*" in 2012 (Evans & Annunziata 2012). The term points towards the meshing of the digital and machine worlds. According to (Evans & Annunziata 2012), *industrial internet* can be defined as the integration of three elements:

- ***Intelligent machines: i.e.*** connecting the worlds' machines and fleet of machines with advanced sensors, controls and software applications.
- ***Advanced analytics:*** Combination of physics-based advanced analytics, predictive algorithms, automation and domain expertise
- ***People at work:*** Connecting people at work or on the move, anytime, to support "more intelligent design, operations, maintenance and higher service quality and safety".

The implementation and gradual adoption of industrial internet and related business models can be a very complex and extensive process of change. It requires the coordinated development of a large number of versatile individual and organizational skills and competencies. Furthermore, one important challenge is that it requires the collaboration of various individuals, business functions, and even various organizations, since the business models often evolve from departmental and factory-level models to inter-organizational and even ecosystem-level business models. Due to the complexity and the extent of the concept, the implementation and adoption of industrial internet can be slow, it is often not very systematic, and decisions and investments are often made that are not optimal from the whole company's point of view.

Businesses often have to implement large and complex intra- and inter-organizational change processes such as those occasioned by Product Lifecycle Management (e.g. Vezzetti et al. 2013), Supply Chain Management (e.g. Wendler 2012) or major investments in IT or technological solutions. In such cases, the technology can drive the implementation process forward too rapidly, in that the human workforce's skills and motivation lag behind the technological/organisational progress. The industrial internet is still a new phenomenon so many companies lack a comprehensive understanding about its purpose and the solutions it can offer. Therefore, companies have to experiment to learn how to proceed. However, many of these experiments fail, as they have not been designed to maximize learning. Thus, businesses need a coordinated and systematic approach to the concept behind the industrial internet in order to increase its penetration into modern industrial production. The maturity modelling approach (Pöppelbuß et al. 2011) is fast being recognised as a useful approach to this problem. Because of its increasing popularity and wide acceptance, we have formulated the objective of this paper, which is: "*to help to design and provide guidelines for a maturity model to achieve a coordinated, systematic and stepwise adoption of the industrial internet and reduce the effort manufacturing enterprises need to implement it*".

The more detailed research questions are:

1. Why would a maturity approach be useful in the implementation of the industrial internet?
2. What are the most important design guidelines for constructing an industrial internet maturity model?

2 Literature Review

2.1 Industrial Internet

In some of the most advanced industrial economies, much attention is given to the latest developments in information and communications technology (ICT). Lately, its influence over industrial manufacturing, i.e. improvements to productivity and efficiency, has grown rapidly with the introduction of *industrial internet* technologies (Posada et al. 2015; Kagermann 2015; Burmeister et al. 2015). It is generally accepted that the adoption of these emerging ICT technologies will increase in coming years and will open up new business opportunities and business model innovations (Posada et al. 2015).

It is over eighty years since Schumpeter (1934) identified innovation as a critical factor for economic change. Schumpeter states that technological innovations can create temporary monopolies that can result in a surge in profits for a company. The *industrial internet* is one such technological innovation in manufacturing industries (Evans & Annunziata 2012; Kagermann et al. 2013). (Burmeister et al. 2015) argue that the *industrial internet,* is mainly about business model innovations in manufacturing industries. Business model innovations require certain skills and competences for their development (Osterwalder et al. 2005) and the early identification of such skills and competencies helps in creating a roadmap to implement increasingly sophisticated and complex business models. For example, (Lazonick & Prencipe 2005) examined complex business models like Rolls Royce Plc to demonstrate how competencies constantly need to be evaluated along with a rapidly changing financial and business environment.

Technological and business model innovations increase the complexity of products and their manufacturing processes. Increases in the functionality and efficiency of a product inevitably increase its complexity. Improvements and optimization in the agility of the production process increase the organizational and technical integration of innovations at different levels within an organisation, and through changing forms of collaboration between different companies (Kagermann 2015). One way to tackle this growing complexity is modeling. Models usually represent a snapshot of a real or hypothetical scenario with certain controlled variables. For complex innovation processes like the *industrial internet*, modeling is one approach to reducing the complexity of the change. There are planning models, explanatory models, value creation models and maturity models, all of which can be used to understand the technical and business processes affected by the *industrial internet* (Kagermann et al. 2013; Burmeister et al. 2015)

2.2 Maturity Model Literature

The concept of maturity has been widely used to describe, compare and determine a path or roadmap for improvements in industry. These improvements usually involve an entity, such as a process, a technology, people and/or organizations moving towards something which is perceived as being highly beneficial for business. The dominant idea is to describe a *path to maturation* (i.e. something better, advanced, higher performance) which is *mostly linear, forward moving* (rarely regressing), and in which the entity improves considerably in terms of the desired results, i.e. capabilities, value creation, performance, etc. Maturity models, also sometimes referred to as stage of growth (SOG) models, helps to capture the interrelationships of the many multifaceted dimensions of this growth and simultaneously providing an artificial construct to measure the concerned entity's progress. The underlying assumption behind maturity models is, the higher the degree of maturity, the higher the positive change in multiple dimensions that contribute to the maturation of the entity in the given context. To date, however, most maturity models have been conceptual (Becker et al. 2009; Wendler 2012), and the assumption of a single linear path being able to encompass several dimensions has been criticized for its lack of a theoretical and academic foundation (King & Kraemer 1984; Pöppelbuß et al. 2011). However, over their 40 year history, various types of maturity models have found wide acceptance among practitioners and researchers, because of the maturity models' facility to offer a *simplistic re-*

ductionist view of a complex problem (Jugdev & Thomas 2002). Maturity models utilize comprehensive sets of criteria for competency, capability, sophistication etc. in a certain domain, and can thus provide practical methods to assess an organization's practices (Jugdev & Thomas 2002).

The literature on maturity models is predominantly focused on developing new models, e.g. business process management (De Bruin et al. 2005), web/social media (Back & Haager 2011; O'Reilly et al. 2012), Analytics (Davenport & Harris 2007) among others. Despite the variety of applications for maturity models, many researchers, (Mettler et al. 2010; Becker et al. 2009; Maximilian Röglinger et al. 2012; Solli-Sæther & Gottschalk 2010) have put a lot of effort into standardizing maturity model development and research by prescribing guidelines, vocabulary and procedures. Maturity model design has been described as an *evolution where new challenges emerge as soon as previous challenges have been solved* (Solli-Sæther & Gottschalk 2010). Steenbergen et al. (2010) follows this paradigm in the science of design, and De Bruin (2005) has proposed a six-phase model for development which utilises the concept of maturity model layers and a schema for defining the general characteristics of the model, such as focus, stakeholders, audience, method of application, respondents, etc.). Based on the design science guidelines proposed by Hevner et al. (2004), Becker et al. (2009) have proposed a detailed 8-step procedure for developing a maturity model as an IT artifact. Furthermore, (Solli-Sæther & Gottschalk 2010) have proposed the stage-modelling process, which defines the core topics in the different stages of growth and defines their dimensions, paths of evolution and major problems on a theoretical level.

2.3 The Industrial Internet and a maturity model approach

Since as long ago as 1993, maturity models have commonly been associated with Capability Maturity Models (CMM). This has resulted in the development of Capability Maturity Model Integration (CMMI) as espoused by Wendler (2012). CMMI is a CMM-rooted framework that includes, for instance, the best practices for developing products and services. However, unlike with CMM models, more recent research into maturity models has shown that they need not be restricted merely to software-related domains (Wendler 2012) or to the evolvement of the maturity of individual company processes. Furthermore, maturity models have found acceptance in a wide variety of application areas and now encompass the maturing of knowledge and data quality, amongst other things. Over the course of three studies, Wendler (2012) shows a total of 20 application domains and 18 application areas in a variety of industries such as IT, manufacturing and services. Even in the adoption and implementation of hugely complex, inter-organizational, multi-process applications, such as those incurred in, for example, Product Lifecycle Management (PLM) (Vezzetti et al. 2013), Supply Chain Management (SCM) (Netland et al. 2007), Social Media (Geyer & Krumay 2015) and Product-Service Systems (Neff et al. 2014). Table 1, below, describes recognized and analyzed Maturity Models (MMs) used for relatively similar but highly complex inter-organizational implementation processes (mainly in the context of manufacturing industries). The table highlights the major similarities and analogies in the analyzed MMs for Industrial Internet implementations, including features such as the objectives of the adoption, the extent of the adoption, and the sources of complexity that this necessarily entails. However, relatively few papers on maturity models, particularly those related to very complex adoption or implementation processes, have reported on the benefits that empirical validation of the models can bring. The advantages of maturity models in the adoption of particularly complex systems include (1) serving as a basis for building a longer-term roadmap for investment decisions or the development of required novel competencies, (2) providing a structured checklist for the implementation, and the management of competencies in the implementation process, (3) making the complex adoption process faster and more efficient, (4) helping to assess the current as-is situation of an implementation in terms of various critical management areas, (5) determining the desired future outcome in an optimal way (Neff et al. 2014; Batenburg et al. 2006; Sharma 2005; Savino et al. 2012; Kärkkäinen et al. 2014; Jussila et al. 2011; Wendler 2012). Time and again, the adoption of complex systems has been significantly slower and less efficient than was expected due to inadequate coordination (Batenburg et al. 2006; Wognum & Kerssens-Van Drongelen 2005) which results in unplanned and unexpected bottle-necks in certain management areas.

Table 1. Maturity Models of complex phenomena analogous to Industrial Internet

Analyzed Maturity Models (MMs)	**Similarities and analogies of analyzed MMs in Industrial Internet implementations (e.g. extent of adoption, sources of complexity in adoption, objectives of adoption)**	**Academic references used in this table**
Product Lifecycle Management (PLM) MMs	• MMs emphasize inter-organizational collaboration especially at higher levels of PLM maturity e.g. (Batenburg et al. 2006) • Adoption involves a multitude of interacting business processes and actors (individuals, functions, organizations) (Batenburg et al. 2006; Sharma 2005) • As in II, PLM adoption is essentially about efficient management and sharing of data, information and knowledge (Kärkkäinen et al. 2012)	(Batenburg et al. 2006; Sharma 2005; Savino et al. 2012); see also lit. reviews of (Vezzetti et al. 2013; Stentzel et al. 2014)
Supply Chain Management (SCM) MMs	• SCM is focused on inter-organizational collaboration along supply chains • Adoption involves a multitude of actors, while focusing on fewer processes related to supply processes • Supply chains may, in many cases, be networks or even ecosystems as in Industrial Internet	(Netland et al. 2007; Archie Lockamy III & Kevin McCormack 2004)
Product-Service Systems (in manufacturing companies) MMs	• Service systems and related MMs need to facilitate inter-organizational collaboration at least in higher levels of maturity • Adoption involves a multitude of actors and processes (both product and service-related) • Service and product data gathering, exploitation and integration is essential in both types of MMs • Product-service systems and related MMs deal closely with development of both services and new business models, analogously to Industrial Internet	(Neff et al. 2014; Rapaccini et al. 2013)
Social Media MMs	• MMs emphasize inter-organizational collaboration and value co-creation especially at higher levels of PLM maturity • Adoption involves a multitude of actors and processes (depending on the topics for which social media is used) • As with Industrial Internet, adoption is essentially about efficient management and sharing of data, information and knowledge e.g. (Kärkkäinen et al. 2012)	(Lehmkuhl et al. 2013; Jussila et al. 2011; Geyer & Krumay 2015)

Thus, it seems reasonable that similar benefits would also be gained in the context of potential maturity models designed for the adoption and implementation of the processes involved with Industrial Internet applications. It is an extremely complex process because of the related development of completely new types of business ecosystems (Kagermann et al. 2013; Posada et al. 2015; Evans & Annunziata 2012), very novel types of business models and value creation models (Posada et al. 2015; Bruner 2013). The industrial internet maturity model also takes into account the transformation of businesses from product-centered to service-centered organizations (Neff et al. 2014), as well as the large number of actors and organizational processes potentially involved in the adoption process (Kagermann 2015; Evans & Annunziata 2012) especially in the later phases of industrial internet adoption.

2.4 Design Guidelines for Industrial Internet Maturity Model

Based on the maturity model design framework (Mettler 2009) for decision-making parameters during the development of a maturity model, development, Table 2 defines the scope and presents the design guidelines for maturity models in an industrial internet context.

Table 2. Maturity Models of complex phenomena analogous to Industrial Internet

Phase	Decision Parameters	Characteristics	Examples	Design Guidelines /Recommendation
Define Scope	Focus/Breadth	Generic Model	Industrial Internet as a phenomenon can be the scope	Industrial Internet as a phenomenon can result in a broad maturity model for a com-

				pany to use.
		Specific Model	Industry Specific, i.e. manufacturing industry (heavy equipment manufacturing industry), IT industry (data analytics, data visualization) Manufacturing-techniques specific i.e. mass manufacturing, engineering to other kinds of manufacturing	A heavy equipment manufacturing company, for example, needs a design based on processes, people and object-related outputs. The maturity model can be based on mass manufacturing, project-oriented manufacturing or engineering for designer manufacturing.
	Audience	Both, Management -oriented and technology oriented audience	Industrial internet is a phenomenon, which involves intelligent machines, advanced analytics and people working together. Hence, it is important to have both technological as well as management oriented needs.	To find out the needs and roles of management and technology personnel in the area of industrial internet in order to keep the context directed at the target audience.
Design Model	Maturity Definition	Combination of Process, people and object-focussed parameters/dimensions	Industrial internet maturity can be defined keeping intelligent machines' maturity, advanced analytics' maturity and people's skills and competences in mind.	Optimization of system of systems involving people and people's capabilities and a multitude of business processes & technologies, including IT and sensors
	Goal Function	Multi-Dimensional	Connectivity (sensor related) and the spread of connectivity over different business units can be examples of two dimensions	Complex processes like the industrial internet require more than one dimension to understand the benefits of their adoption.
	Design Process	Literature and Practitioner Based	PLM, Supply Chain Management, Service System related maturity models	Take analogous models from literature (Table 1) and discuss the pros and cons with industry practitioners.
	Application Method	Self-Assessment or Third Party certified professional	Self-assessment if industry professional is designing the model for the same industry evaluation	Depending on the audience and respondents the model should be applied either by the industry or by third party professionals
	Respondents	Combination of internal (staff and administration) and external (Business partners)		If model is applied internally, Management & Staff are respondents and if it is applied externally to an industrial ecosystem, then the business partners are the respondents

Mettler (2009) emphasizes that it is important to define the focus of the phenomenon to be studied using an appropriate maturity model. Any Industrial Internet implementation demands a specific technological and strategic implementation in a company's business process. In order to fully understand the effects of the implementation of industrial internet, a more specific (industry specific, domain specific, production method specific) maturity model is required to define the breadth of the model. The Industrial Internet is of particular significance to manufacturing industries and Information Technology (IT). This allows us to tailor the maturity model for the implementation of industrial internet towards the manufacturing industries, especially heavy equipment manufacturing. Global companies like GE, Siemens and Kone cranes, which are active in the heavy equipment manufacturing sector, and IT and IT-service companies like Intel, Cisco and AT&T would all benefit from a maturity model fashioned according to industrial internet design guidelines (Agarwal & Brem 2015; Neff et al. 2014; Bruner 2013). The goods and equipment that are produced by the heavy equipment manufacturing industry are characterized as long lasting and highly productive. Hence, processes such as maintenance, repair and change operations are very important capabilities for these industries to have in order to achieve and maintain high profit margins (Neff et al. 2014). The scope and the focus of an industrial internet maturity model for heavy equipment manufacturing can be further refined based on the production techniques, i.e. mass production or bespoke engineering techniques. PLM maturity models are a good case for portraying models based on production techniques, i.e. mass production, project-specific production or engineered-to-order production techniques (Table 1).

Given that the implementation of industrial internet is both a business and technological innovation affecting an organization's business strategy (Kagermann et al. 2013; Evans & Annunziata 2012; Agarwal & Brem 2015), the audience (Mettler 2009) for the industrial internet maturity model in the heavy equipment manufacturing industry will encompass both technology-oriented and management-oriented personnel (Mettler 2009). This is similar to what happens with the social media maturity models in B2C and B2B (Lehmkuhl et al. 2013; Jussila et al. 2011) where it is important to assess the maturity of an organization from both the management technological perspectives. The Industrial Internet is well defined as being at the convergence of three essential elements: intelligent machines, advanced analytics and people at work (Evans & Annunziata 2012), and as such it involves the optimization of a large system of systems (Evans & Annunziata 2012; Bruner 2013; Agarwal & Brem 2015; Kagermann et al. 2013). The Industrial Internet incorporates all three elements of any manufacturing business' system, i.e. processes, people and objects (Mettler 2009; Neff et al. 2014; De Bruin et al. 2005). Hence, maturity for industrial internet can be defined as the optimization of the system of systems involving people and their capabilities, a multitude of business processes, and different technologies including sensors and IT.

The complexity of industrial internet means that its maturity will influence process functions (e.g. efficiency, optimization), technologies and IT-related functions, and people's capabilities and skills. Hence, any study of the effects of the adoption of industrial internet, demands a multi-dimensional approach, which will provide a wide range of relevant information. The same applies to other complex process like PLM maturity design (Kärkkäinen et al. 2014), in which the design process of the model has to be based on a combination of literature and the practical, experience-based knowledge held by industry-based professionals. Table 1 shows comparable models to the industrial internet which can be used as benchmarks in designing the model for industrial internet. The method of application for any such model has to be planned and designed for systems built by external professionals based on academic research or by industry insiders using their own practical experience. If the maturity management model is used for internal evaluation, then the respondents will be internal managers and technical experts. If the model is used to analyse an industrial ecosystem, then the model will be aimed at the external business partners.

3 Research Design

3.1 Overview

(Mettler 2009) has defined and categorised the design parameters to be used when developing a maturity model. In this paper we present the design guidelines for developing a maturity model for industrial internet using the design guidelines from the developer's perspective (Mettler 2009), complemented with the design principles for maturity models recommended by Pöppelbus (2011). An Action Design Research (ADR) (Sein et al. 2011) methodology will be used to create and validate the model, which is appropriate for the nature of the problem and the ensemble artefact. While developing a maturity model as an ensemble artefact in industrial internet, it is important to design, shape and reshape the ensemble artefact (maturity model in this case) as well as to have interventions in the organizational work practices while the evaluation of the ensemble artefact is ongoing. This approach is the key reason to use ADR as a methodology (Sein et al. 2011). We use the design guidelines presented in this paper to create a conceptual maturity model of industrial internet, making use of the analogous models referred to above in this paper (both structure and content), as well as the literature on industrial internet implementations and its success factors. The dimensions and the levels of this conceptual model will be presented to senior managers and technical experts from 15 global pioneers in industrial internet solutions, manufacturing and IT companies. They will be interviewed about the dimensions and the levels of maturity of the conceptual model, and their responses will be utilised in designing, shaping and reshaping the ensemble artefact (the maturity model, in this case). Once this has been done, the finished maturity model will be presented to the same set of managers and technical experts, who will implement it in a workshop environment in their own company or industry in order to assess its effectiveness. The desired outcome of this workshop will be the validation of the maturity model for industrial internet.

3.2 Data Collection and Analysis

In the interviews with the industry experts we will look for experience-based advice about the design guidelines and the conceptual model proposed in this paper. The experience-based advice will be regarded s as existing theories-in-use about the industrial internet and associated maturity models. The interviews will proceed with the following structure:

1. The interviewees will *identify and define the concepts* presented in the conceptual maturity model and the design guidelines used to create the conceptual maturity model.
2. The interviewees will *evaluate and rank* the preferences they have propose in the previous step.
3. We will *record the findings* during the interviews, to refine the conceptual maturity model and the design guidelines that led to the creation of the model.

Based on the recorded findings of the interviews, the existing literature on the industrial internet and research on maturity models and design frameworks (Mettler 2009), we will revise the construct and finalize the construction of the maturity model. In the final workshop with the same set of industry experts, we will present the final maturity model construct. Our experts will super-impose this model on their respective company's business practices in the area of industrial internet, and provide feedback and validation. Finally, we will triangulate the data from the workshop, the industrial internet literature and the literature on maturity models to present the final construct of the maturity model to the IS community.

4 Conclusion & Expected Contributions

The research design outlined so far describes a comprehensive research process to develop a maturity model framework in the context of the industrial internet. This will be based on literature and our experts' own, practical experience with the implementation of industrial internet in heavy equipment manufacturing industries operating in the mass production of industrial goods (e.g. in the metals and electronics industries). The research design will clearly contribute towards the very scarce literature on the industrial internet and the related development of a specific maturity model. From a managerial perspective, the resulting industrial internet maturity framework will enable the company to assess the as-is situation of their industrial internet adoption. It will also aid the company in determining future targets and provide a roadmap for future investment and endeavours in facilitating their own industrial internet activities and business models. A maturity model framework in industrial internet will allow industry to have a common language of communication while discussing the current situation and planning the future development of industrial internet amongst interested professionals from various backgrounds (for example, amongst mechanical engineers, software engineers and managers in the same company). In this research in progress paper we have argued why a maturity model approach might not only be possible, but also useful in very complex inter-organizational implementation processes such as those demanded by the industrial internet. We also categorically state the benefits of having a maturity approach to implementing industrial internet. Finally, we have provided guidelines for developing an industrial internet maturity model. This will be built using (Mettler 2009) the Mettler framework (2009), and will demonstrate which decisions should be made in the early phases of the model design, and some major options for these decisions. We will make use of ADR as a methodology to develop the model, and validate it using interviews and workshop methods. This will provide maturity model designers with clear guidelines on how to build an industrial internet maturity model.

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