Digital Transformation to Industry 4.0 Maturity Index

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Abstract
Digital transformation may be defined as the impact of changes on several dimensions of the organization driven by digital technology or other factors, such as the business models it enables. Digital transformation is a global market with vertical markets as customers. Amongst these customers are manufacturing industries, where digital transformation may be called Industry 4.0. One of the overview management tools is the digital maturity index, which combines several organizational dimensions with capability maturity stages. The tool is a radar chart. Its main use is diagnostic. The goal of this article is to describe and analyze a new management tool, the digital maturity index, according to the main proposals of management consultants, scientific literature, and Siemens. The methodology is an instrumental case study on Siemens. It performs a literature review and finds commonalities in the digital transformation maturity stages in maturity indices and Lee's 5C architecture. Literature review and the Siemens case study identify the same maturity stages towards Industry 4.0 as in the working group proposal: connectivity; conversion; cyber; cognition; configuration. The Siemens case study shows each level of maturity corresponds to technologies used to design cyber-physical systems. Digital transformation impacts a wide variety of dimensions, with many different representations in the literature review. At Siemens, the main dimensions of digital transformation are digital technology, digital processes, and digital business models. Digital processes shift from the automation pyramid to the digitalization network. Digital business models move from rigid value chains to flexible value networks. At Siemens and in the proposal of the Industry 4.0 working group, digital transformation is impacted by the strategy for digital transformation, Smart Innovation.

Keywords
Digital transformation; digital maturity index; innovation strategy; organizational dimensions; business processes; business models; maturity stages.

Introduction

This article is one of two complementary articles about Industry 4.0 maturity indices: the first article tackles the topic of maturity indices to the Industry 4.0 level of digital maturity. The first article aims to demonstrate that an important part of Industry 4.0 maturity indices matches Lee's 5C architecture for cyber-physical systems. Another aim is to match technologies that are needed to design and operate cyber-physical systems, as per Porter and Heppelmann's articles, with the digital transformation stages to Industry 4.0. In the complementary article presented at this conference, the stages of digital maturity are described beyond Industry 4.0. The aim is to show newer more advanced technologies have already emerged, are complementary with existing technologies and with business dimensions of digital transformation like digital disruption, the outcome economy. The goal of these two-article series is to describe and analyze a new management tool, the digital maturity index, according to the main proposals of management consultants, scientific literature, and Siemens. The article thereby intends an overview of digital transformation to Industry 4.0 that highlights the stages of maturity and organizational dimensions involved. The potential impact of the article is high and gives its instrumental nature.

Literature review shows maturity indices are an important overview tool in digital transformation decisions, with theoretical and practical implications. From a theoretical point of view, maturity indices review a large body of literature and structure it in a pattern. Typically, the research presents the maturity index but not the arguments for it. Maturity indices have been elaborated by management consultants beginning in 2010 and by scientific literature beginning in 2016; this makes it possible in 2021 to review the most important references and compare. Literature review defines the role of maturity indices as overview and diagnostic. This is an argument for the instrumental role of maturity indices.

The article finds maturity indices converge on Lee's 5C architecture. The stages in maturity indices point to the technologies that help design and operate cyber-physical systems: cloud, analytics, digital twin and digital thread, artificial intelligence. These technologies are needed in this order to digitally transform to Industry 4.0, and the functionality of each stage depends on predecessors. The technologies are included in the digital transformation market, where sellers or consultants are referred to in the literature review for digital maturity index proposals; however, it is the buyers of these technologies that will shape digital transformation. This is another argument that makes the maturity index instrumental. The choice of methodology – a descriptive and instrumental case study - is argued by the impact on digital transformation theory and practice. The relevance of the maturity index to customer markets' digital transformation decisions gives its empirical value. This is an original approach that builds on past research from the authors, where several articles have addressed the digital transformation maturity index since 2018 with similar conclusions.

Two articles published in 2018 have noted several stages towards Industry 4.0 which are made in sequential order: connectivity, analytics, digital twin, cyber-physical systems, and systems of systems of cyber-physical systems. The technologies have impacted several organizational dimensions: digital technology, business processes, business models. The articles provide early on empirical evidence on Industry 4.0. In a subsequent article in 2019, a maturity scale was induced and constructed based on these stages of digital maturity, where the induction shows Lee's 5C architecture. The authors' research effort includes using the digital maturity index as a diagnostic tool for the solutions to COVID-19, by performing a maturity diagnostic to identify the level of maturity and the gap to the work from anywhere operating model enabled by digitalization. In 2021, an additional article shows global market analyzes that prove automation, cloud, and analytics mark the global level of digital transformation maturity giving the capabilities to weather the Covid crisis. These two articles may be used as arguments towards the instrumental nature of this approach. This is a consistent coherent research effort on behalf of the authors and includes a book in process of editing.

Literature review

Mainframe consultants (BCG, 2021; CapGemini, 2011; Deloitte, 2020; Gartner, 2021; IBM Institute for Business Value, 2011; IDC, 2021; Markets & Markets, 2021; The World Economic Forum, 2020a, 2020b) and scientific resources (Bharadwaj et al., 2013, Kavadias et al., 2016; Morakanyane et al., 2017; Nwaiwu, 2018; Porter & Heppelmann, 2014, 2015; Kane et al., 2016; Tabrizi et al., 2019; Yablonksky, 2018; Westermann et al., 2014a; Westermann et al., 2014b) define digital transformation as the impact of changes on several dimensions of the organization driven by digital technology or other factors, such as the business models it enables. Digital transformation is a new management phenomenon, with new definitions. Digital transformation is also the name for the market that includes digital technology and its society-wide impact (IDC, 2021; Markets & Markets, 2021; Statista, 2021). The main market analyst, IDC, is broadly recognized as the leader for digital transformation analyzes. Digital transformation induced by information technology may be defined by IDC's platforms (IDC, 2020): the first platform comprises the mainframe terminal and has millions of users; since 1985, the second platform comprises the Lan/Internet and client/ server and has hundreds of millions of users; the third platform lasts since 2011, the change extends to billions of users and comprises cloud, big data analytics, social business, mobility and technology accelerators; the latter consist of robotics, natural interfaces, 3D printing, Internet of Things, cognitive systems, and next-generation security.

The digital transformation market is expected (IDC, 2019) to be large and grow fast, from 1.2 trillion USD in 2020 to 2.3 trillion USD by 2025. It is by this date IDC expects the number of digital transformation adept companies to rise from 27% to 73% (IScoop, 2021). The digital transformation market comprises several markets, which include cloud, analytics, Product Lifecycle Management software for the digital twin, artificial intelligence (IDC, 2010; Markets & Markets, 2021). The digital transformation market has several vertical markets as customers, where manufacturing markets are but one group of markets (IDC, 2021; Markets & Markets, 2021; Statista, 2021). In manufacturing, digital transformation may be called Industry 4.0 (Kagermann et al., 2013; Kagermann, 2015). This view recognizes several waves of industrial technology: mechanization, Industry 1.0; electrification, Industry 2.0; automation, Industry 3.0; digitalization, Industry 4.0. In manufacturing, digital transformation is a dual innovation strategy (Kagermann, 2015): explorative and exploitative both (Kagermann et al., 2015). This involves: optimizing the core, with existing technological capabilities and existing business models; reshaping the core, which is the business transformation for the new normal; creating the new, that is a new technology with a new business model (Kagermann, 2015). Porter and Heppelmann (2014, 2015) notice new products, smart connected products, with new business models, will create new markets and disrupt existing ones.

Maturity models represent a theory of staged-based evolution and its basic purpose, which consists of describing stages and maturation paths through a scale of maturity

(Bertolini et al., 2019). Mettler (2009, 2011) defines maturity as a development of a specific ability or reaching a targeted success from an initial to an anticipated stage. In this view, the most popular Industry 4.0 maturity model proponents, Schumacher, Eroll, and Sihn (2016) maturity models are a tool for comparing current maturity level to the desired maturity level of an organization or process, by conceptualizing and measuring. Maturity systems increase their capabilities over time regarding the achievement of some future state. This definition is shared by other popular authors such as Proença and Borbinha (2016), and Mittal et al. (2018). According to Proença and Borbinha (2016), maturity models can be used as evaluation criteria and described as complete, perfect, or ready. Maturity models may be used from progression from the basic state to a more advanced final state. The role of maturity models is complex: audit; benchmark; process appraisal; organization appraisal; progress tracking; diagnostic (Proença & Borbinha, 2016). Maturity models are models that help an individual or entity to reach a more sophisticated maturity level, in people/ culture, processes/ structures, and or objects/ technologies following a step-by-step continuous improvement process (Mittal et al., 2018). Maturity models are questionnaires with several options to choose from for each question (Akdil et al., 2017). Nickkhou et al. (2016) defined maturity as guidance to correct or prevent problems, evidence of an achievement or a perfect state to be reached. Maturity models enable organizations to audit and benchmark assessment results; track the process towards the desired level; evaluate strengths, weaknesses, threats, and opportunities; to sequence, stages from basic to advanced. Tarhan, et al. (2016) describe maturity models as desired logical path for processes in several business fields which include discrete levels of maturity. According to Backlund et al. (2014), maturity models are extremely important tools to appraise organizations. Schumacher et al. (2019) categorize maturity models into two groups: holistic approaches and specific approaches.

Holistic approaches aim to assess and utilize elements of Industry 4.0 from all possible angles. They may be used to derive encompassing success factors. Specific approaches focus on a limited number of aspects relevant to Industry 4.0 with greater detail. Industry 4.0 capability maturity models are traced to this framework and advanced in software and Industry 4.0 (Colli et al., 2019; Wendler, 2012). In Industry 4.0, maturity models are organizational capabilities, include a stream of objectives and sequential levels or stages (Sener & Gokalp, 2018). In 1986, the capability maturity model was created by the US Department of Defense. In the capability maturity model, maturity levels are given by progressive capabilities that describe how the behaviors, practices, and processes of an organization can reliably and sustainably produce required outcomes (Nayab, 2010). The maturity levels are initial; repeatable; defined; capable; efficient. In digital transformation, maturity indices refer to processes and other organizational dimensions and have several capability maturity levels.

Maturity levels comprise the stages of digital transformation. Maturity scales may be divided into two categories, where some follow Lee's 5C (Lee et al., 2015) architecture for cyber-physical systems: first level, connection, sends data to the cloud; the second level, conversion, mines this data for patterns to improve performance up to predictive maintenance; the third level, cyber, creates a virtual twin of physical properties; the fourth level, cognition, enables cyber-physical systems to make decisions for themselves and the systems of systems they form; the fifth level, configuration, brings self-configure, self-adjust, self-optimize. A readiness opinion comes from EDP Singapore, McKinsey & Company, Siemens, SAP, and TÜV SÜD (2019) who prepare an Industry 4.0 readiness index that comprises vertical integration, horizontal integration, and integrated lifecycle as preconditions to achieve Industry 4.0 and technology maturity stages automaton, connectivity, intelligence. Furthermore, many scales consider Industry 4.0 maturity in relation to the 5C architecture. Knowledge Exchange and Fraunhofer (2016) and Acatech (2016) have highly similar maturity scales, with the following stages: the starting point, Industry 3.0; visibility, answering what happens?; transparency, answering what will happen?; predictability, answering what will happen?; adaptability, answering how an autonomous reaction can succeed? CapGemini's 2018 version of the maturity index follows maturity stages: computerization and connectivity; visibility and transparency; predictive power; adaptability and self-learning. McKinsey (2016) has a similar approach to capability maturity levels: data-driven insights; integrated customer experience; digital marketing; digitally-enabled operations; next-gen technology; digital enablers. Porter and Heppelmann (2014, 2015) consider the following levels of maturity: monitoring, control, optimization, autonomy. Considering a scientific approach to digital technology, Lee (2015) views the following levels of cyber-physical systems: connection; conversion; cyber; cognition; configuration. Qin et al. (2016) consider the starting point of current manufacturing systems and the transition to digitalization: digitalization; communication; standardization; flexibility; customization; real-time responsibility; predictive maintenance; decision making; early aware; self-optimization; self-configuration; stages differ based on the current level of technological advancement of the starting industry.

Weber et al. (2017) look at the following stages of maturity: non-existent IT integration; data and system integration; integration of cross-life-cycle data; service-orientation; digital twin; self-optimizing factory. Sjodin et al. (2018) come close to the cyber-physical systems maturity stages and consider connected technologies, structured data collection and sharing, real-time process analysis and optimization, intelligent and predictive manufacturing. Klötzer and Pflaum (2017) consider maturity stages: digitalization awareness; smart networked products; the service-oriented enterprise; thinking in service systems; the data-driven enterprise. Scientifically accredited literature reviews about maturity assessment (Colli et al., 2019) conclude maturity stages in the largest part of maturity scales include the following stages: none, basic, transparent, aware, autonomous, and integrated. At a basic level, digital data are generated (machines on the production floor generate digital data related to their process) collected and handled locally. Transparent means data is available across the organization according to value streams needs (alert data from the equipment are collected and transmitted to the service department). The aware level involves data that is structured and transmitted according to recognized standards, is analyzed to capture valuable information to understand the business insights (proactive activities identification by crossing error data, product number, machine downtime, etc.). Autonomous decision making is performed autonomously based on automatically synchronized data, structured and transmitted following a universal standard, from the organization and its direct customers and suppliers (logistics scheduling is automatically performed based on production state, customer orders and location, traffic condition, etc.). Integrated means decision-making is performed autonomously based on automatically synchronized data from the whole organization's network (suppliers' suppliers and customers' customers).

Maturity index dimensions refer to the aspects of the organization impacted by digital transformation. As an overall pattern, the automation pyramid will be replaced by digitalization networks (Alcacer & Macado, 2019; Lee et al., 2015; Zeid et al., 2019). Distributed network systems are formed within and across industries (Kagermann et al., 2015). Digital transformation may have designated names by the customer industry. Platform Industry 4.0 (2017) tackles digital transformation as synonymous with Industry 4.0. In the original vision, Industry 4.0 is a transformation triggered by the Internet of Things, data and services (Kagermann et al., 2013, p. 7). Accordingly: "the real-time networking of products, processes, and infrastructure is ushering in the fourth industrial revolution where supply, manufacturing, maintenance, delivery and customer service are all connected via the Internet. Rigid value chains are being transformed into highly flexible value networks." (Kagermann et al., 2013, p. 7). Organizational dimensions correspond to the organizational areas impacted by digital transformation as per definition. Organizational dimensions vary highly in management literature in the view of proponents. According to CapGemeni (2011), organizational dimensions are business model: digitally modified business, new digital business, and digital globalization; operational or process: process digitalization, worker enablement, and performance management; customer experience: customer understanding, top-line growth, and customer touchpoints. Although Knowledge Exchange and Fraunhofer (2016) and Acatech (2016) have highly similar scales, dimensions differ. Knowledge Exchange and Fraunhofer (2016) consider digital transformation refers to the following organizational dimensions: smart solutions; smart innovation; smart networks; smart connected supply chains; smart production; data-driven business models; digital strategy and vision; digital strategy and vision; information technologies; resources; culture and mindset. Acatech (2017) includes the following dimensions: resources; informational systems; organizational structure; culture in their assessment of Industry 4.0.

The IMPULS (Lichtblau, 2015) scale comprises the following dimensions: organizational strategy; smart factory; smart operation; smart products; data-driven services; employees. In, 2018, Akdil et al include the following dimensions in digital transformation: smart products and services; smart business processes (research and development, production, marketing and sales, supportive operations); strategy and organization (business models, strategic partnerships, technology investments, organizational structure, and leadership). Deloitte's (2018) approach look at the network capabilities cyber-physical systems of systems provide in the following maturity stages: flexible, secure infrastructure; data mastery; digitally savvy, open talent networks; ecosystem engagement; intelligent workflows; unified customer experience; business model adaptability. PWC (2016) looks at the following organizational dimensions: digital business models and customer access; digitization of product and service offerings; digitization of vertical and horizontal value chains; data and analytics as core capability; agile IT architecture; compliance, security, legal, and tax; organization, employees and digital culture. Many other opinions exist.

Methodology

This instrumental case study takes the Siemens example to describe, analyze and characterize a management tool for a new phenomenon, the digital transformation index. The case study is both exploratory and instrumental. The exploration involves discovering empirical evidence about the digital transformation maturity index used by Siemens Digital Transformation Business Unit Advanta. The evidence may be explicit about the maturity index. The evidence may also pertain to the dimensions of digital transformation: digital technology, business processes, business models, innovation. Digital technology is explored individually: Internet of Things platform; Product Lifecycle Management software; artificial intelligence; cyber-physical systems; additive manufacturing; blockchain. Evidence about business processes is related to each technology type and each stage of maturity. Innovation is treated as the strategy for the entire digital transformation, A large variety of Siemens' statements explore, describe and explain business processes and business models at each stage of digital maturity. This information is explored, described, analyzed. The instrumental approach takes the organizational dimensions and stages of maturity as argued in a variety of presentations and structures this information to construct Siemens' digital transformation maturity index in all its details. The instrumental nature of the case study is given by the use of the maturity index internally at Siemens and externally in digital transformation consulting for all Siemens' customers.

Empirical analysis of the Siemens case – maturity levels of the customer offering

Overview of the Siemens case

Siemens is one of the key market players in the convergence of information technology and operational technology markets (Gartner, 2017). Siemens is reported as a leader in several digital transformation technologies: cyber-physical systems, Product Lifecycle Management software, Internet of Things platforms. At Siemens, innovation in core technology electrification, automation, and digitalization is marketed on all verticals. Digitalization involves several technologies, which are used by all Siemens' vertical markets (manufacturing, infrastructure, mobility, and carve-outs). At Siemens, Advanta is a central unit in charge of digital transformation consulting (Siemens, 2021a, p. 32). Siemens Advanta enables companies to unlock the digital future by supporting their unique digitalization journey from start to finish (Siemens, 2021a, p. 32). Siemens has worked with PWC (2018) to support digital transformation consulting. The digital consulting framework contains the digitalization maturity scale as a key tool in managing digital transformation (Siemens, 2018c, p. 19; Siemens, 2020a). Digital transformation is at the heart of Siemens' businesses (Siemens, 2021a, p. 8). Leading in all businesses and shaping the digital transformation is intended from 2021 onwards.

Siemens' digitalization maturity scale

Siemens defines digitalization as leveraging digital technology for concrete customer benefits (Siemens, 2016a, p. 16; 2016b, p. 4; 2016c, p. 5). Digital transformation is defined as a change in the way value is created in an organization, via changes in business models, business processes, or organizational setup triggered by digital technology (Siemens, 2019e). Siemens' maturity scale shows several stages of digital transformation to Industry 4.0 (CIMdata, 2019; Siemens, 2017c, p. 13) comprises the following stages: connectivity; descriptive, diagnostic, and predictive analytics; closed-loop innovation; augmented reality, virtual reality; artificial intelligence and cognitive capabilities; self-optimizing systems; additive manufacturing; disruption, new business models and the outcome economy; blockchain. Digitalization maturity (Siemens, 2018c, p. 13) is a function of digital twin and digital thread complexity. In Siemens's digital maturity assessments, digital technology, business processes, and business models are the most frequently considered dimensions of change (Siemens, 2020b). Siemens works with PWC (2018), which defines the dimensions of digital transformation as strategic: digital strategy and business models; digital operating model, processes, structure, and culture; technological infrastructure and digital manufacturing processes. Digital maturity indices are the first step in digital transformation consulting (Siemens, 2018c, p. 19; 2020a).

First steps: connecting assets to the Internet and providing analytics based maintenance services

Industry 4.0 means manufacturing based on cyber-physical systems. In one view, cyber-physical systems begin as connected devices, go on as smart devices and culminate in application empowered interacting devices (Siemens, 2015b, p. 6). Siemens launched its platform Mindsphere, which by 2017 has become Siemens Internet of Things operating system (Siemens, 2017n, pp. 19 – 23; 2018a, p. 21). Siemens claims Mindsphere is its new platform for data-based services (Siemens, 2016a, p. 6). Mindsphere is used for analytics services (Siemens, 2018e, p. 2). Mindsphere comprises Mindconnect, Mindsphere, and Mindapps (Siemens, 2019d, p. 8). Mindconnect is a secure plug-and-play connection of Siemens and third-party products and equipment (Siemens, 2019d, p. 8). Mindsphere is Open Platform as a Service (PaaS) for scalable, global IoT connectivity, application development, and deployment (Siemens, 2019d, p. 8). MindApps are powerful industry applications and digital services leveraging best-in-class cloud technologies (Siemens, 2019d, p. 8). Mindsphere impacts functions: customer relationship management, marketing, and sales; research and development; operations, production and information technology; service and support (Siemens, 2017a, p. 15). Mindsphere is the solution to continuously evaluate components' power consumption, with specific recommendations to optimize configuration. It generates optimized energy consumption (Siemens, 2017b, p. 14).

Steps already reached by today: digital transformation via digital twins and the digital thread they create

Siemens (2015a) writes about smart connected products that are transforming every industry, moving innovation from incremental to transformational. Examples are autonomous vehicles, medical implants, self-optimizing energy systems, industrial machinery. Transformational innovation involves creating new business models and attacking new markets (Siemens, 2015a). Innovation makes competition a game between disruptors and victims of disruption (Siemens, 2015a). Digitalization is understood as a strategy to respond to disruptive innovation (Siemens, 2015a). Siemens' innovation strategy, Smart Innovation, is about weaving a digital thread of knowledge throughout the innovation process (Siemens, 2015a). The Smart Innovation strategy is about initiating or responding to disruptive innovation. Smart Innovation is Siemens' strategy for Industry 4.0 and begins with the digital twin and digital thread in Product Lifecycle Management software.

The digital product twin is defined by Siemens (Siemens, 2017b, pp. 23, 24) to be used in product design and includes 3D models (using CAD systems); system models (using system engineering product development solutions, such as systems-driven product development); bill of materials; 1D, 2D and 3D analysis models (using CAE systems); digital software design and testing (using ALM systems); electronic design. The digital twin of products is the key to Product Lifecycle Management software (Siemens, 2016c, pp. 30, 31) and incorporated in Mindsphere (Siemens, 2017b, pp. 24, 25). Alternatively, Siemens (2019c, p. 16) defines the digital product twin as a solution to design, simulate, and verify products digitally, including mechanics and multi-physics, electronics and management of software. According to Siemens (2017b, pp. 23, 24). the digital production twin includes manufacturing process model – the "how – resulting in an accurate description as to how this product will be produced; production facility model – providing a full digital representation of the production and assembly lines needed to make the product; production facility automation model – describing how the automation system (SCADA, PLC, HMI, etc.) will support the production system. The production twin refers to production and logistics processes. The digital twin of production processes is key to Product Lifecycle Management software (Siemens, 2016c, pp. 30, 31) and incorporated in Mindsphere (Siemens, 2017b, p. 25). The digital production twin is defined by Siemens as a tool to plan, simulate, predict, and optimize production digitally including code generation and virtual commissioning (Siemens, 2019c, p. 20). The digital performance twin (Siemens, 2017b, pp. 23, 24) and MindSphere enable Siemens' customer companies to connect with the real-world product, plants, machines, and systems, to extract and analyze actual performance and utilization data. The digital twin of analytics is incorporated in both Product Lifecycle Management processes (Siemens, 2016c, pp. 30, 31) and Mindsphere (Siemens, 2017b, p. 26).

Siemens integrates product and production lifecycles in preparing the ground for Industry 4.0 (Siemens, 2013, p. 8). The digital thread is the progressive accumulation of information in the digital twin from one stage of the product lifecycle to the other. The digital thread unites the digital product twin, the digital production twin, the digital performance twin and transmits virtual information progressively from one product lifecycle to the next that is progressively from product design to production planning, production engineering, production execution, and service. The digital thread combines all product lifecycle stages, the engineering perspective, the operations perspective, and the maintenance management perspective (Siemens, 2019a, p. 6). Product Lifecycle Management software and Mindsphere create a digital thread that unites the product digital twin, the production digital twin, and the performance digital twin (Siemens, 2018g, p. 21; 2018f, p. 33). This is called closed-loop innovation (Siemens, 2018g, pp. 20, 23). Together, Product Lifecycle Management software and Supply Chain Management software form the Digital Collaboration Platform. Achieving closed-loop innovation boosts innovation: electronics manufacturing, IOT/ edge, digital factory, additive manufacturing, generative engineering, autonomous/ electrification (Siemens, 2018b). At Siemens (2021b), autonomous driving solutions for customers already exist.

Steps that reach Industry 4.0 core technology: cyber-physical systems working across the Internet of Things and Internet of Services with new processes and business models

The Smart Innovation strategy (Siemens, 2015a) is intended towards creating smart networked devices or cyber-physical systems in all industries, but particularly autonomous vehicles and manufacturing equipment. In 2014, Siemens announces its research agenda for cyber-physical systems: level system, level processes, level strategy (Siemens, 2014, p. 11). The first level of research for cyber-physical systems refers to cyber-physical systems as modular, autonomous production units. At the system level, a research direction is a vertical integration and networked production systems. This targets flexible production based on modular, autonomous, production units. The research topic is: "How can the production system using cyber-physical systems be flexible reconfigurable and adaptable?" (Siemens, 2014, p. 11). Industry 4.0 impacts every company in several dimensions, where smart products are the digitalization of product and service offerings (Siemens, 2017c, p. 4; 2018d, pp. 16 – 18). Cyber-physical systems are the core technology in Industry 4.0. Cyber-physical systems may be defined as distributed interacting autonomous devices which negotiate and coordinate processes and are application empowered (Siemens, 2015b, p. 6; 2016d, p. 11). One type of cyber-physical system as product innovation, advanced with autonomous driving technology and electrification, is autonomous vehicles (Siemens, 2018b). Other examples of smart connected products (Siemens, 2015a) in the Smart Innovation strategy are medical implants, self-optimizing energy systems, industrial machinery.

Research and development process level 2 means business processes are designed throughout with cyber-physical systems and form systems of systems. At the process level, end-to-end engineering across the entire value chain follows. This tackles the integration of product and production lifecycle: from design to production to service and loop-back. The research topic is: "How can business processes including engineering workflows be designed throughout with cyber-physical systems?" (Siemens, 2017c, p. 4; 2018d, pp. 19 – 33). The digitalization and integration of vertical and horizontal value chains are two of the dimensions Industry 4.0 impacts, creating the smart factory and smart plant. According to Siemens, Industry 4.0 represents a new level of organization and control of the entire value chain, across the life cycle of products, which encompasses all phases from the idea and the order to development and production, delivery of a product to the end customer, even recycling and related services (Siemens, 2016c, p. 10). Advancing machines with artificial intelligence allows them to negotiate decisions as peers to peers for themselves and the system as a whole. The 2013 (Siemens, 2013, p. 55) and 2014 (Siemens, 2014, p. 13) visions for Industry 4.0 are self-organization of integrated production installations considering the entire value chain and flexible decision on production process based on the current situation (Siemens, 2014, pp. 13, 14).

Research and development process level 3: ecosystem-level - new business models, Internet of Things Mindsphere, and Mendix platforms support. At the strategy level lies horizontal integration through value networks, referring to new business models and eco-systems. The research topic is "How can the business strategy of a company and new types of value networks be supported by cyber-physical systems?" Siemens foresees one possible scenario for Industry 4.0: machines will organize themselves to a great extent; delivery chains will automatically assemble themselves; orders will be transformed directly into production information and flow into the production process (Siemens, 2013, p. 55). To achieve this, processes and procedures will still be conceived in advance (Siemens, 2013, p. 55). Siemens researches how cyber-physical systems can support integrated supply chains and ecosystems of partners that bring new business models (Siemens, 2014, p. 11). This level, horizontal integration, belongs to new business models in the entire supply chain (Siemens, 2014, p. 11). One of the dimensions of Industry 4.0 is innovative digital business models (Siemens, 2017c, p. 4; 2017d, p. 9; Siemens, 2018d, pp. 34 – 41). Siemens also believes Industry 4.0 is increasingly geared to individualized customer wishes (Siemens, 2016c, pp. 45, 46). Flexible production networks (Siemens, 2017d) support new business models, such as the separation of Product Lifecycle Management and Supply Chain Management.

Conclusions

A large number of maturity indices, including Acatech's and Siemens', agree that digital transformation from Industry 3.0, automation, to Industry 4.0, digitalization, comprises the five maturity stages in Lee's 5C architecture (Lee et al., 2015): connectivity; conversion; cyber; cognition; configuration. There are other types of maturity indices, where one measures digital maturity in terms of excellence or performance. Maturity indices highlight the impact of the new technologies on several organizational dimensions, where the main ones remain business processes and business models. Whereas digital maturity indices tend to be abstract, the Siemens case shows they correspond to a series of technologies that work progressively and accretively towards cyber-physical systems and the systems of systems these form. The first level of maturity involves connecting devices to the cloud and generating big data. In the second stage, analytics technology will mine the data for patterns and create algorithms. At the third level, the full digital twins of product and production in Product Lifecycle Management software are merged with the predictive digital performance twin in the digital thread. At the fourth level of digital maturity, artificial intelligence enables devices to make decisions and create systems of systems that make common decisions, such as scheduling. Systems of systems of cyber-physical systems change supply chain management processes and business models. At the highest level of digital maturity, these systems are autonomous. Each level of digital maturity corresponds to a group of technologies, and they too correspond to individual markets.

According to the proponent of Industry 4.0, Kagermann (2015), Porter and Heppelmann (2014, 2015), and Siemens, the strategy to realize digital transformation is an innovation strategy that will culminate in new products, cyber-physical systems as products or smart connected products, and new platform business models. Smart connected or cyber-physical products are often (Porter & Heppelmann, 2015, 2015) mentioned as the goal of digital transformation. Porter and Hepplemann (2014, 2015) mention product-service system solutions which include systems of systems, distributed networks of cyber-physical systems that change the automation pyramid to the digitalization network. These will form the smart factories and smart supply chains of tomorrow, with several platform-based business models possible. Maturity indices have emerged around 2010 for management consultants and 2016 in the scientific literature review. By 2021, opinions converge about maturity stages. Most authors agree business processes and business models will shift from the automation pyramid to the digitalization network, but a wide variety of opinions exist about organizational dimensions impacted.

As far as Siemens is concerned, Smart Innovation is software the company markets as the strategy for digital transformation. The Smart Innovation strategy builds on the Mindsphere platform as a service that is merged with the digital twin and digital thread. This enables cyber-physical systems to be created and operated. Further consideration needs to be made about the role of innovation in digital transformation.

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