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The Stages of Digital Transformation in Manufacturing Industries according to Industry 4.0

Ioan Petrişor,[1] Diana Cozmiuc[2]

[1] West University Timisoara, Romania, ipetrisor53@yahoo.fr
[2] West University Timisoara, Romania, diana.cozmiuc.record@gmail.com

Abstract: *In the years 2010 – 2020, the Industrial Economy has been transforming into the Knowledge Economy at a much faster pace and greater scale than ever in history. Digital technology, generally understood as IDC's third platform, impacts and changes businesses, industries, society in a process called digital transformation. All industries are impacted and disrupted in a digital vortex. In manufacturing industries, digital transformation comprises Industry 4.0, which may be understood as the fourth generation of manufacturing technology, digitalization, that follows automation, electrification and mechanization; an emerging market for a group of technologies; a vision for the future of manufacturing industries; a national competitiveness strategy for Germany and Europe. Industry 4.0 will bring new manufacturing technology: big data, autonomous robots, simulation, horizontal and vertical system integration, internet of things, cloud computing, additive manufacturing, augmented reality and cyber security - that will replace existing manufacturing technology in a boom. The first step to Industry 4.0 will generate big data to the cloud and the internet of things. It will pave the way to the digital twin of physical reality in virtual reality via simulation, horizontal and vertical system integration. Once the full digital twin of physical reality is created, the full step to Industry 4.0 will be achieved by cyber-physical systems, which will transform manufacturing capabilities via new processes, new business models, new forms of value and performance. Organizations will be digitally transformed into digital enterprises; value chains will be transformed into value networks; digital strategy and execution will be reinvented. This chapter is a case study about digital transformation at Siemens' customers, the leading market share of manufacturers.*

Keywords: *digital technology, digital transformation, digital disruption, Industry 4.0, digital maturity, operational processes, business models*

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Ioan Petrişor, Diana Cozmiuc
West University Timişoara, Romania

I. Introduction

Between 2010 and 2020, Industrial Economy has transformed into Knowledge Economy at a much faster pace and greater scale than ever in history. Digital technology, generally understood as IDC's third platform, impacts and changes businesses, industries, and the society in a process called digital transformation. In businesses, there are several elements of digital transformation, the most important of which are business models. Innovations in digital technology and in new business models change the dynamics of competition in a new game called digital disruption, the replacement of incumbents by new entrants. Existing industries are disrupted by innovations in digital technology and in business models to a different extent in a digital vortex. Among these industries are manufacturing industries, which are disrupted by digital manufacturing technology, alternatively called Industry 4.0 or the Industrial Internet. Industry 4.0 is a new generation of manufacturing technology, digitalization, that succeeds automation, electrification and mechanization. Siemens is one of the key players on this market, and the Siemens case will be relevant for an important market sample, Siemens' customers, as well as for their competitors and Siemens'. Industry 4.0 will transform enterprises, especially their processes and business models. The Industry 4.0 market will evolve in several stages: the connection of devices to the Internet of Things and Internet of Services, the realization of the digital twin of mechanics, electronics and software, the transformation of manufacturing processes via cyber-physical systems. Along with technology, business models and organizations will also evolve. The paper has been disseminated in two articles indexed Web of Science[1] and three articles indexed Scopus.[2] This research is a literature review about Industry 4.0 key topics, which focuses on the Siemens

[1] D. Cozmiuc, I. Petrişor, "Industrie 4.0 by Siemens - steps made next," *Journal of Cases on Information Technology* 20(1) (2018).

[2] D. Cozmiuc, I. Petrişor, "Innovation in the age of digital disruption, the case of Siemens," in *Strategic Innovation Management for Competitive Advantage* (Pennsylvania: IGI Global, 2018); D. Cozmiuc, I. Petrişor, "Siemens' customer value proposition for the migration of legacy devices to cyber-physical systems in Industrie 4.0," *Analyzing the Impacts of Industry 4.0 in Modern Business Environments* (Pennsylvania: IGI Global, 2018); I. Petrişor, D. Cozmiuc, "Global Supply Chain Management Organization at Siemens in the Advent of Industry 4.0," *Global Intermediation and Logistics Service Providers* (Pennsylvania: IGI Global, 2017).

customer offering case study. The research summarizes the key aspects of digital transformation and digital disruption in manufacturing, Industry 4.0. The purpose of this paper is to serve as overview about the Industry 4.0 market in all its aspects, which culminates in a digital maturity scale proposal for organizations and groups of organizations in industries or nations. Industry 4.0 is a topic for research institutes, governments, manufacturing organizations, non-governmental organizations, consultants, journal articles, books, market reports, cited fully in the original articles and book chapters that inspired this book chapter and only partly in this book chapter for reasons of length. The literature review synthesizes sources such as the IDC accepted digitalization consultants on digital technology and digital transformation, main literature on disruption, digital disruption and business models, Industry 4.0 technology reports, market reports, and market vision, Siemens' technology customer offering and its business impact, Industry 4.0 business models, Industry 4.0 maturity assessment scales. The Siemens case is used as an important opinion about the future of Industry 4.0, that will shape many customers. The paper structures this literature in a logical course that parts from general to specific. The paper finds digital technology in manufacturing and digital transformation in manufacturing have different stages of evolution and degrees of maturity.

II. Stages of digital transformation in manufacturing industries according to Industry 4.0 – Siemens' customer offer

1. Digital transformation

The Industrial Economy is transforming in the Knowledge Economy in several progressive stages. Digital technology has inflicted several waves of fast and high-scale change to the Industrial Economy[3]. These changes may be represented as the decades of the Knowledge Economy: in the 1990s, the emergence of the Knowledge Economy, with digital products and infrastructure; in the 2000s, digital distribution and web strategy; since 2010, digital transformation of business models. Digital technology, created by digitization, may be defined as the IDC's third platform. The third platform comprises cloud, big data analytics, social business, mobility and technology accelerators which consist of robotics, natural interfaces, 3D printing, Internet of Things, cognitive systems, next generation security. Digitalization technology transforms individual industries[4]. Digitalization is defined[5] as the use of

[3] IBM Institute for Business Value, *Digital transformation. Creating new business models where digital meets physical*, 2011,
https://www-935.ibm.com/services/in/gbs/thoughtleadership/ibv-digital-transformation.html (last time accessed: March 20th, 2017); IDC, *Explore 3rd Platform Transformation*, http://www.idc.com/promo/thirdplatform, 2017 (last time accessed: May 23rd, 2018).

[4] World Economic Forum, *Digital disruption has only just begun*, 2016,
https://www.weforum.org/agenda/2016/01/digital-disruption-has-only-just-begun/ (last time accessed: March 20th, 2017).

[5] CapGemeni, *Digital Transformation: a Roadmap for Billion-Dollar Organizations*, 2011,

digital technologies to change a business model and provide value-creating opportunities or improve performance quantifiably.

According to IBM Institute for Business Value Analysis[6], digital transformation is the pervasive degree of economic impact digital technology has on functions, industries, society. IDC[7] describes digital transformation as the use of digital technologies in ways that were never anticipated. Innovations driven by digital technologies are expected to bring about unprecedented business transformation, representing the biggest industry shakeout since the Industrial Revolution. Digital transformation [8] is the use of technology to radically improve performance or reach of enterprises – via change customer relationships, internal processes, and value propositions, the blocks of digital transformation. These blocks of digital transformation may be used to assess digital maturity. One of the most famous studies about digital transformation is an MIT Center for Digital Business and CapGemeni Consulting study since 2011. In this view, digital transformation is a journey in several stages or degrees of maturity, which cover the what and the how; digital capabilities such as business model, operational process, customer experience; strategic assets and digital investment in an iterative transformation roadmap. Digital maturity blends digital intensity and transformation management intensity, which are both low for beginners; high and low respectively for fashionistas; low and high respectively for conservatives; both high for digirati. Digital transformation has many shapes of impact: digital reengineering, value chain transformation, digital value proposition, business model reinvention[9].

https://www.capgemini.com/resourcefileccess/resource/pdf/Digital_Transformation__A_Road-Map_for_Billion-Dollar_Organizations.pdf (last time accessed: March 20th, 2017); Gartner, *Gartner Analytics Evolution Framework*, 2018, https://www.gartner.com/en/documents/3891974 (last time accessed: May 23rd, 2018); IBM Institute for Business Value, *Digital transformation. Creating new business models where digital meets physical,* 2011, https://www-935.ibm.com/services/in/gbs/thoughtleadership/ibv-digital-transformation.html (last time accessed: March 20th, 2017); IDC, *Explore 3rd Platform Transformation*, 2017, http://www.idc.com/promo/thirdplatform (last time accessed: May 23rd, 2018).

[6] IBM Institute for Business Value, *Digital transformation*, 2016, http://www.01.ibm.com/common/ssi/cgibin/ssialias?infotype=PMandsubtype=XBandappname=GBSE_GB_TI_USENandhtmlfid=GBE03399USENandattachment=GBE03399USEN.PDF (last time accessed: May 23rd, 2018).

[7] IDC, *Explore 3rd Platform Transformation*, 2017, http://www.idc.com/promo/thirdplatform (last time accessed: May 23rd, 2018).

[8] CapGemeni, *Digital Transformation: a Roadmap for Billion-Dollar Organizations*, 2011, https://www.capgemini.com/resource-fileccess/resource/pdf/Digital_Transformation__A_Road-Map_for_Billion-Dollar_Organizations.pdf (last time accessed: March 20th, 2017).

[9] IDC, *Explore 3rd Platform Transformation*, 2017, http://www.idc.com/promo/thirdplatform (last time accessed: May 23rd, 2018).

IDC reports show information technology is about to disrupt all industries. IDC[10] defines digital disruption as the continuous process through which companies adapt to or dictate disruptive changes in their clients and markets (external ecosystem), by managing digital competencies to innovate business models, products, and services which blend digitalization, physical aspects, business or customer experience while they improve operational effectiveness and organizational performance. Digital disruption[11] occurs when digital technology[12] replace incumbents' business models in industries with new business models. According to several articles in Harvard Business Review, for example Grossman[13], digital disruption will impact all industries in different degrees, generally described as a digital vortex.

2. Industry 4.0

Industry 4.0 is a new generation of industrial technology, digitalization, that succeeds automation in years 1969-2020, the assembly line years 1870-1969, steam and mechanics 1700-1860[14]. The vision behind Industry 4.0 is Plattform Industrie 4.0. According to some sources, Industry 4.0 or the Industrial Internet is the part of digital technology that pertains to manufacturing industries. Industry 4.0 is an alternative name for the Internet of Things in manufacturing industries[15], synonymous with advanced manufacturing, cyber-physical systems, the intelligent factory, the Industrial Internet. According to the digital technology analyst Gartner[16],

[10] IDC, *Explore 3rd Platform Transformation,* 2017, http://www.idc.com/promo/thirdplatform (last time accessed: May 23rd, 2018).
[11] CapGemeni, *Industry 4.0 - The Capgemini Consulting View*, 2016, https:// www.de.capgemini-consulting.com/resource-file-access/resource/pdf/capgemini-consulting-industrie-4.0_0.pdf (last time accessed: March 20th, 2017); Grossman, R., "The Industries that are being disrupted the most by digital," *Harvard Business Review*, (March 2016); G. Westerman, D. Bonnet, A. McAfee, "Digital Transformation: A Roadmap for Billion-Dollar Organizations," *Harvard Business Review Press* (2014); G. Westerman, D. Bonnet, A. McAfee, "Leading Digital. Turning Technology into Business Transformation," *Harvard Business Review Press* (2014).
[12] IDC, *Explore 3rd Platform Transformation*, 2017, http://www.idc.com/promo/thirdplatform (last time accessed: May 23rd, 2018).
[13] R. Grossman, "The Industries that are being disrupted the most by digital," *Harvard Business Review* (March 2016).
[14] H. Kagermann, *Recommendations for implementing the strategic initiative Industrie 4.0: Final report of the Industrie 4.0 Working Group*, 2013, http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report__Industrie_4.0_accessible.pdf (last time accessed: March 20th, 2017).
[15] European Parliament, *Industry 4.0 Digitalisation for Productivity and Growth,* 2015, http://www.europarl.europa.eu/RegData/etudes/BRIE/2015/568337/EPRS_BRI(2015)568337_EN.pdf (last time accessed: March 20th, 2017)*;* European Parliament, *Industry 4.0. Study for the ITRE Committee*, 2016, http://www.europarl.europa.eu/RegData/etudes/STUD/2016/570007/IPOL_STU(2016)570007_EN.pdf (last time accessed: March 20th, 2017).
[16] Gartner, Predicts 2017: Industrie 4.0,

Industry 4.0 means digitalizing complex value chains. According to the same source, Gartner[17], digitalization is the use of digital technology to change a business model, offer new revenue and new value creation opportunities; the process of moving on to a digital business. Digital technology is the Internet of Things[18].

Industry 4.0 is the market of digital technology in manufacturing activity. Analysts suggest the Industry 4.0 will be massive[19]. Digital market analyst Gartner believes the Internet of Things will reach 3700 USD by 2020. Consultant KPMG states a rough estimation of current analysts for the Industry 4.0 market indicates 4000 billion USD by 2020. The European Parliament[20] cites Roland Berger consultants and estimates that by 2030 the Industry 4.0 investment will reach 1350 billion Euros in Europe alone. Based on Gartner's statements, Deloitte and Council of Competitiveness have estimated the Internet of Things market to reach 5649 billion USD by 2019[21]. The Markets and Markets report[22] point to 152 billion USD until 2020, with 14.72% per annuum. Morgan Stanley also believes that, by 2020, the cyber security market will reach 183 billion USD. IDC digital technology analyst believes the market for virtual and augmented reality in Industry 4.0 will reach 162 billion USD[23]. As companies do not report individual sales by product group, the actual market is difficult to estimate.

There are several interpretations of the technology included in Industry 4.0. The essential technology for Industry 4.0 is made up by cyber-physical systems, which create products, manufacturing equipment and intelligent logistics equipment; intelligent factories which run over the Internet of Things; intelligent supply chains which run over the Internet of Services[24]. The Industry 4.0 vision is supported by

https://www.gartner.com/doc/3571817/predicts--industrie-(last time accessed: May 23rd, 2018).

[17] Gartner, *Digitalization*, http://www.gartner.com/it-glossary/digitalization/ (last time accessed: May 23rd, 2018).

[18] Gartner, *Cool Vendors in Digitalization Through Industrie 4.0,* 2017*,* https://www.gartner.com/doc/3741617/cool-vendors-digitalization-industrie- (last time accessed: May 23rd, 2018).

[19] KPMG, *The fourth industrial revolution. How does the factory of tomorrow look like*?, 2015, https://www.kpmg.com/TR/en/hizmetlerimiz/Advisory/management-consulting/Documents/industry-4.pdf (last time accessed: March 20th, 2017).

[20] European Parliament, *Industry 4.0 Digitalisation for productivity and growth*, 2015, http://www.europarl.europa.eu/RegData/etudes/BRIE/2015/568337/EPRS_BRI (2015) 568337_EN.pdf.

[21] Deloitte, *Disruption In Manufacturing*, 2016, https://www2.deloitte.com/content/dam/Deloitte/us/Documents/risk/us-risk-disrupt-manufacturing.pdf (last time accessed: March 20th, 2017).

[22] Deloitte, *The smart factory. Responsive, adaptive, connected manufacturing,* 2017, https://dupress.deloitte.com/dup-us-en/focus/industry-4-0/smart-factory-connected-manufacturing.html (last time accessed: May 23rd, 2018).

[23] KPMG, *The fourth industrial revolution. How does the factory of tomorrow look like?,* 2015, https://www.kpmg.com/TR/en/hizmetlerimiz/Advisory/management-consulting/Documents/industry-4.pdf (last time accessed: March 20th, 2017).

[24] M. Hermann, T. Pentek, B. Otto, *Design Principles for Industrie 4.0 Scenarios: A Literature Review,* 2014, http://www.thiagobranquinho.com/wp-content/uploads/2016/11/Design-

Product Lifecycle Management software for vertical integration; product lifecycle integration via digitalization; horizontal integration[25]. Close to the original vision, Deloitte[26] identifies vertical integration, product lifecycle integration and horizontal integration via cyber-physical systems as foundational technologies for Industry 4.0, and accelerated technology such as the 3D printer. Boston Consulting Group[27] includes in Industry 4.0 big data and analytics, autonomous robots, simulation, horizontal and vertical integration, the Industrial Internet of Things, cyber security, cloud, additive manufacturing, augmented reality. Cyberphysical systems may be included in the Internet of Things. Markets and Markets identify Industry 4.0 as market[28] with the following subcomponents: industrial robotics, cyber security, the Internet of Things, the 3D printer, advanced human-machine interface, big data, augmented and virtual reality, artificial intelligence. According to PriceWaterhouse Coopers[29], Industry 4.0 technology comprises cloud, mobility, Internet of Things platforms, localization detection technology, advanced human machine interface,

Principles-for-Industrie-4_0-Scenarios.pdf (last time accessed: March 20th, 2017); H. Kagermann, *Recommendations for implementing the strategic initiative Industrie 4.0: Final report of the Industrie 4.0 Working Group,* 2013, http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report__Industrie_4.0_accessible.pdf (last time accessed: March 20th, 2017).

[25] Boston Consulting Group, *Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries,* 2015, https://www.bcgperspectives.com/content/articles/engineered_products_project_business_industry_40_future_productivity_growth_manufacturing_industries/?chapter=2 (last time accessed: March 20th, 2017); M. Hermann, T. Pentek, B. Otto, *Design Principles for Industrie 4.0 Scenarios: A Literature Review,* 2014, http://www.thiagobranquinho.com/wp-content/uploads/2016/11/Design-Principles-for-Industrie-4_0-Scenarios.pdf (last time accessed: March 20th, 2017); H. Kagermann, *Recommendations for implementing the strategic initiative Industrie 4.0: Final report of the Industrie 4.0 Working Group,* 2013, http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report__Industrie_4.0_accessible.pdf (last time accessed: March 20th, 2017).

[26] Deloitte, *Industry 4.0 Challenges and Solutions for the Digital Transformation and Use of Exponential Technologies,* 2015, https://www2.deloitte.com/content/dam/Deloitte/ch/Documents/manufacturing/ch-en-manufacturing-industry-4-0-24102014.pdf (last time accessed: March 20th, 2017).

[27] Boston Consulting Group, *Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries,* 2015, https://www.bcgperspectives.com/content/articles/engineered_products_project_business_industry_40_future_productivity_growth_manufacturing_industries/?chapter=2 (last time accessed: March 20th, 2017).

[28] Markets and Markets, *Industry 4.0 Market worth 152.31 Billion USD by 2022,* 2017, http://www.marketsandmarkets.com/PressReleases/industry-4.asp (last time accessed: May 23rd, 2018).

[29] PriceWaterhouse Coopers, *Industry 4.0: Building the digital enterprise,* 2016, https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digitalenterprise-april-2016.pdf (last time accessed: March 20th, 2017).

fraud authentication and detection, the 3D printer, intelligent sensors, big data analytics and advanced algorithms, multilevel customer and customer profile interaction, augmented reality. These make up digitalization and horizontal and vertical value chain integration; the digitalization of products and services; digital business models and customer access. World Economic Forum[30] includes the following technology in Industry 4.0: sensors, RFID, machine to machine communication, robotics, 3D printer, drones, blockchain, virtual and augmented reality, artificial intelligence. In the view of this book chapter, the migration to Industry 4.0 will take place in several steps: the first step is the connection of devices to the Internet of Things and the generation of big data; the second step brings the full digital twin of mechanical, electronical and software properties and enables cyber-physical technology; the third step is cyber-physical systems based manufacturing.

Industry 4.0 is the digital disruption in manufacturing. According to the original proponents of Industry 4.0[31], Industry 4.0 is synonymous with the digital disruption in manufacturing industries. The European Parliament acknowledges this logic of Industry 4.0 and calls the new technology potentially disruptive innovation[32]. Value creation via new business models leads to the replacement of old technology with new technology. In the vision of Industry 4.0, devices are connected to the Internet, are cyber-physical systems and capable of negotiating among themselves infinitely complex decisions with intelligence and autonomy[33]. The peer to peer negotiation of cyber-physical systems is called disruptive digital technology. Roland Berger[34] calls Industry 4.0 a quick, disruptive, destructive and irreversible technology. In Industry

[30] World Economic Forum, *Digital Transformation of Industries*, 2016, http://reports.weforum.org/digital-transformation/wpcontent/blogs.dir/94/mp/files/pages/files/digital-enterprisenarrative-final-january-2016.pdf (last time accessed: March 20th, 2017).

[31] H. Kagermann, *Recommendations for implementing the strategic initiative Industrie 4.0: Final report of the Industrie 4.0 Working Group,* 2013, http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report__Industrie_4.0_accessible.pdf (last time accessed: March 20th, 2017); Plattform Industrie 4.0, *Plattform Industrie 4.0, 2014: Industrie 4.0. Whitepaper FuEThemen,* 2014, http://www.plattformi40.de/sites/default/files/Whitepaper_Forschung%20Stand%203.%20April%202014_0.pdf (last time accessed: March 20th, 2017).

[32] European Parliament, *Industry 4.0 Digitalisation for productivity and growth,* 2015, http://www.europarl.europa.eu/RegData/etudes/BRIE/2015/568337/EPRS_BRI(2015)568337_EN.pdf (last time accessed: March 20th, 2017)

[33] H. Kagermann, *Recommendations for implementing the strategic initiative Industrie 4.0: Final report of the Industrie 4.0 Working Group,* 2013, http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report__Industrie_4.0_accessible.pdf (last time accessed: March 20th, 2017).

[34] Roland Berger Consultants, *Industry 4.0: a real quantum leap,* 2015, https://www.rolandberger.com/en/Blog/Industry-4.0-quantum-leap.html (last time accessed: March 20th, 2017).

4.0, disruptive digital technology is tied to the Internet of Things, cyber-physical systems, robots, intelligent cars, big data, new connectivity quality, energy efficiency and decentralization, virtual industrialization, 4.0 factory. Value creation via business models replaces old technology with new technology[35].

Several companies are anticipated as key players on the Industry 4.0 market, as suppliers or customers. The Industry 4.0 effort involves cooperation, where the progress of European companies towards Industry 4.0 is monitored as such by the author group, Plattform Industry 4.0[36]. In Europe, the main companies which migrate towards Industry 4.0 include Siemens. According to the Markets and Markets report about Industry 4.0[37], Siemens is one of key market players. According to the Roland Berger[38] study, Industry 4.0 pioneers are Trumpf, Siemens, Rolls-Royce, Dassault Systemes.

3. Stages to Industry 4.0

The transition to Industry 4.0 will occur in several stages: the connection of industrial devices to the Internet of Things, that will generate big data to the cloud, which using analytics will be used to improve performance; the ground setting for Industry 4.0, technology that allows vertical integration, end-to-end integration and horizontal integration; the migration of current manufacturing technology to the full Industry 4.0 vision, manufacturing using cyber-physical systems across the Internet of Things and Internet of Services creating smart products, smart manufacturing equipment, smart factories, smart logistics systems, smart supply chains; further technological evolution from artificial intelligence, for example robotics, additive manufacturing. The adoption of Industry 4.0 technology, processes, business models, value drivers and other is a gradual approach in several stages of maturity. For example, at CapGemeni, digital maturity is the beginning of the digital transformation towards Industry 4.0, equivalent to digitalization in manufacturing industries[39].

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[35] European Parliament, *Industry 4.0 Digitalisation for productivity and growth,* 2015, http://www.europarl.europa.eu/RegData/etudes/BRIE/2015/568337/EPRS_BRI(2015)568337_EN.pdf (last time accessed: March 20th, 2017); European Parliament, *Industry 4.0. Study for the ITRE Committee,* 2016, http://www.europarl.europa.eu/RegData/etudes/STUD/2016/570007/IPOL_STU(2016)570007_EN.pdf (last time accessed: March 20th, 2017).

[36] Plattform Industrie 4.0, *Plattform Industrie 4.0, 2014: Industrie 4.0. Whitepaper FuEThemen*, 2014. http://www.plattformi40.de/sites/default/files/Whitepaper_Forschung%20Stand%203.%20April%202014_0.pdf (last time accessed: March 20th, 2017).

[37] Markets and Markets, *Industry 4.0 Market worth 152.31 Billion USD by 2022*, 2017, *http://www.marketsandmarkets.com/PressReleases/industry-4.asp* (last time accessed: March 20th, 2017)

38 Roland Berger Consultants, *Industry 4.0: a real quantum leap,* 2015, https://www.rolandberger.com/en/Blog/Industry-4.0-quantum-leap.html (last time accessed: March 20th, 2017).

[39] Capgemeni, *Crafting a Compelling Digital Customer Experience,* 2014,

In the first stage, devices: manufacturing equipment, logistics systems are connected to the Internet of Things, generate big data to the cloud, which data is turned into smart data by several types of analytics in Gartner's evolution model[40]: descriptive analytics (what happened?), diagnostic analytics (why did it happen?), predictive analytics (what will happen?), prescriptive analytics (how can we make it happen?). At this stage, the manufacturing schedule will be decided via current automation solutions, such as Enterprise Resource Planning where the most famous supplier is SAP. Customer orders are placed into the system, and matched with the bill of materials to make out the materials needed and with the bill of process or routing to make out the manufacturing processes. Both bill of materials and bill of processes or routing are generated by Product Lifecycle Management systems. The bill of materials corresponds to product design and its constituent components. The bill of processes is a list of manufacturing activities needed to assemble components into the final product. The product is identified by the customer order.

This paper relies on several articles about Industry 4.0 from the authors, one which asserts Product Lifecycle Management software as the solution to the transition to Industry 4.0[41] and is indexed Web of Science, and other two book chapters indexed Scopus which cover open innovation and supply chain integration in the advent of Industry 4.0[42]. In the Industry 4.0 scenario, the transition to the full vision depends on three preceeding stages: the vertical integration of the value chain; the end-to-end integration of the value chain; the horizontal integration of the value chain. This is the second stage to Industry 4.0. Industry 4.0 is defined by its proponents as "…a new level of value chain organization and management across the lifecycle of products…"[43]. The proponents of the leading consultants in digital transformation refer to these elements of Industry 4.0: the vertical integration of the value chain; the end-to-end engineering of the product lifecycle; the horizontal engineering of the supply chain – as key. Technology research confirms: vertical integration of the value chain, end-to-end engineering of the product lifecycle and

https://www.capgemini.com/resources/digital-transformation-review-6 (last time accessed: March 20th, 2017).

[40] Gartner, *Gartner Analytics Evolution Framework,* 2018,
https://www.gartner.com/en/documents/3891974 (last time accessed: May 23rd, 2018).

[41] D. Cozmiuc, I. Petrişor, "Industrie 4.0 by Siemens - steps made today," *Journal of Cases on Information Technology* 20(2) (2018).

[42] D. Cozmiuc, I. Petrişor, Innovation in the age of digital disruption, the case of Siemens, *Strategic Innovation Management for Competitive Advantage* (Pennsylvania: IGI Global, 2017); I. Petrişor, D. Cozmiuc, "Global Supply Chain Management Organization at Siemens in the Advent of Industry 4.0," *Global Intermediation and Logistics Service Providers*(Pennsylvania: IGI Global, 2017).

[43] Plattform Industrie 4.0, *Plattform Industrie 4.0, 2014: Industrie 4.0. Whitepaper FuEThemen*, 2014,
http://www.plattformi40.de/sites/default/files/Whitepaper_Forschung%20Stand%20 3.%20April%202014_0.pdf (last time accessed: March 20th, 2017).

horizontal integration of the supply chain are preconditions of Industry 4.0[44] and are achieved via the Product Lifecycle Management software solution. This stage of transition achieves the full digital twin or virtual copy of resources, processes, factory and furthermore supply chain. This digital twin will be used to upgrade manufacturing equipment from automation to digitalization, cyber-physical systems. The achievement of this stage conditions the full Industry 4.0 vision, manufacturing using cyber-physical systems.

Furthermore, the full Industry 4.0 vision is depicted in an article indexed Web of Science by the authors[45]. The authors argue growing complexity across the supply chain motivates Industry 4.0[46]. In the smart factory, a new type of device emerges[47]: the cyber-physical system, which is a cyber-physical product which negotiates with cyber-physical factory equipment its design needs[48]. Smart products negotiate with smart equipment production steps and are able to evaluate the stage of completion of their product design and the quality of manufacturing. They thereby make decisions such as manufacturing schedule, logistics schedule, supply chain management. Smart production equipment is cyber-physical and able to negotiate production processes for itself and the system it is part of, that is the smart factory[49].

[44] D. Cozmiuc, I. Petrişor, "Industrie 4.0 by Siemens - steps made today," *Journal of Cases on Information Technology* 20(2) (2018).

[45] D. Cozmiuc, I. Petrişor, "Industrie 4.0 by Siemens - steps made next," *Journal of Cases on Information Technology* 20(1) (2018).

[46] D. Cozmiuc, I. Petrişor, "Global Supply Chain Management Organization at Siemens in the Advent of Industry 4.0," *Global Intermediation and Logistics Service Providers* (Pennsylvania: IGI Global, 2017).

[47] CapGemeni, *Industry 4.0 - The Capgemini Consulting View*, 2016, https://www.de.capgemini-consulting.com/resource-file-access/resource/pdf/capgemini-consulting-industrie-4.0_0.pdf (last time accessed: March 20th, 2017); The Digital Manufacturing and Design Innovation Institute, *Join the Revolution in American Manufacturing*, 2016, http://dmdii.uilabs.org/(last time accessed: March 20th, 2017); H. Kagermann, *Recommendations for implementing the strategic initiative Industrie 4.0: Final report of the Industrie 4.0 Working Group*, 2013, http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report__Industrie_4.0_accessible.pdf (last time accessed: March 20th, 2017); KPMG, *The fourth industrial revolution. How does the factory of tomorrow look like?,* 2015, https://www.kpmg.com/TR/en/hizmetlerimiz/Advisory/management-consulting/Documents/industry-4.pdf (last time accessed: March 20th, 2017); PriceWaterhouse Coopers, *Industry 4.0: Building the digital enterprise,* 2016, https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digitalenterprise-april-2016.pdf (last time accessed: March 20th, 2017).

[48] CapGemeni, *Industry 4.0 - The Capgemini Consulting View*, 2016, https://www.de.capgemini-consulting.com/resource-file-access/resource/pdf/capgemini-consulting-industrie-4.0_0.pdf (last time accessed: March 20th, 2017).

[49] The Digital Manufacturing and Design Innovation Institute, *Join the Revolution in American Manufacturing*, 2016, http://dmdii.uilabs.org/(last time accessed: March 20th, 2017); H.

According to proponent of the model, Kagermann, the integration of the Internet of Things (IoT) and the Internet of Services (IoS) in the manufacturing process has initiated Industry 4.0, the fourth industrial revolution[50]. In this proposal: "Industry 4.0 is focused on creating smart products, procedures and processes"; "smart factories constitute a key feature of Industry 4.0"; "smart factories are capable of managing complexity, are less prone to disruption and are able to manufacture goods more efficiently". This will create tomorrow's smart infrastructures that will transform conventional value chains with the emergence of new business models. The main business model is mass customization; today's factory must meet complex products with a high degree of specialization, products must be personalized requiring flexible and agile response to meet the needs of modern customers[51]. Product complexity and variety intertwine[52]. In the vision of Industry 4.0: "in essence, Industry 4.0 will involve the technical integration of cyber-physical systems into manufacturing and logistics and the use of the Internet of Things and Services in industrial processes. This will have implications for value creation, business models, downstream services and work organisation. By the inter-corporation horizontal integration, related corporations can form an efficient ecosystem, in which information, finance, and material flow fluently and new value networks business models may emerge. One business model for Industry 4.0, mass customization, begins with the customer order and involves the entire supply

Kagermann, *Recommendations for implementing the strategic initiative Industrie 4.0: Final report of the Industrie 4.0 Working Group,* 2013, http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report__Industrie_4.0_accessible.pdf (last time accessed: March 20th, 2017); KPMG, *The fourth industrial revolution. How does the factory of tomorrow look like?,* 2015, https://www.kpmg.com/TR/en/hizmetlerimiz/Advisory/management-consulting/Documents/industry-4.pdf (last time accessed: March 20th, 2017); PriceWaterhouse Coopers, *Industry 4.0: Building the digital enterprise*, 2016, https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digitalenterprise-april-2016.pdf (last time accessed: March 20th, 2017); H. Kagermann, *Recommendations for implementing the strategic initiative Industrie 4.0: Final report of the Industrie 4.0 Working Group,* 2013, http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report__Industrie_4.0_accessible.pdf (last time accessed: March 20th, 2017).

[50] I. Veza, M. Mladineo, N. Gjeldum, "Managing Innovative Production Network of Smart Factories," *IFAC-PapersOnLine*, 48(3) (2015).

[51] H. Kagermann, *Recommendations for implementing the strategic initiative Industrie 4.0: Final report of the Industrie 4.0 Working Group,* 2013, http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report__Industrie_4.0_accessible.pdf (last time accessed: March 20th, 2017).

[52] M. Kumari, M. S. Kulkarni, "A complexity based look-ahead mechanism for shop floor decision making," *Procedia CIRP* 41(2016): 63–68.

network which is integrated across the lifecycle"[53]. Complexity is a new metric for manufacturing[54]. Modern manufacturing systems are largely characterised by growing complexity, in manufacturing systems, products, processes, company structures. Cyber-physical systems are a solution to manage complexity that involves the entire supply chain, and form agile collaboration networks or connected supply chains. Agile collaboration networks describe the shift in horizontal integration towards a flexibly defined extended enterprise[55]. They also enable manufacturers to focus on core competences while allowing them to offer customized products in any market. Connected supply chains are the outcome of end-to-end lifecycle process integration, by allowing the seamless integration and automation of physical processes.

The stages of Industry 4.0 are consistent with the development levels of cyber-physical systems, the 5C architecture[56]. This 5C architecture comprises five levels: connection level (conditioned based monitoring, the connection to the Internet of Things which allows the generation of big data), conversion level (data is converted into useful information, such as degradation and performance prediction, multi-dimensional data correlation, component machine health, by using data analytics technology), cyber level (the full digital, cyber of virtual twin of physical properties), cognition level (collaborative diagnostics and decision making, remote visualization for human and integrated simulation and synthesis), and configuration level (corrective and preventive decisions, which has been made in cognition level, to the monitored system). The evolution of Industry 4.0 according to the levels of technology advancement of cyber-physical systems has been argued in one of the articles indexed Web of Science that support this chapter).

4. The Siemens case for Industry 4.0

In what follows, Siemens' exact statements about Industry 4.0 are presented as they were communicated by Siemens at the time the articles were written[57]. Sources from

[53] CapGemeni, *Industry 4.0 - The Capgemini Consulting View*, 2016, https://www.de.capgemini-consulting.com/resource-file-access/resource/pdf/capgemini-consulting-industrie-4.0_0.pdf (last time accessed: March 20th, 2017); PriceWaterhouse Coopers, *Industry 4.0: Building the digital enterprise*, 2016, https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digitalenterprise-april-2016.pdf (last time accessed: March 20th, 2017).

[54] M. Kumari, M.S. Kulkarni, "A complexity based look-ahead mechanism for shop floor decision making," *Procedia CIRP* 41(2016): 63–68.

[55] CapGemeni, *Industry 4.0 - The Capgemini Consulting View*, 2016, https://www.de.capgemini-consulting.com/resource-file-access/resource/pdf/capgemini-consulting-industrie-4.0_0.pdf (last time accessed: March 20th, 2017).

[56] J. Lee, B. Bagheri, H. Kao, "A Cyber-Physical Systems architecture for Industry 4.0 based manufacturing, "*Manufacturing Letters* 3(2015): 18–23.

[57] D. Cozmiuc, I. Petrişor, "Industrie 4.0 by Siemens - steps made next," *Journal of Cases on Information Technology* 20(1) (2018); D. Cozmiuc, I. Petrişor, "Innovation in the age of digital disruption, the case of Siemens," *Strategic Innovation Management for Competitive Advantage* (Pennsylvania: IGI Global, 2018); D. Cozmiuc, I. Petrişor, "Siemens' customer value

Siemens are secondary sources from Siemens, such as various Web site sources, Web available presentations, Siemens annual reports covering years 1998 – 2019. Siemens conceives Product Lifecycle Management as a strategy for customers that supports vertical integration, end-to-end engineering and horizontal integration design and planning requirements of Industry 4.0. The Siemens Product Lifecycle Management portfolio is called smart innovation. In the Siemens portfolio, several solutions come into play to aid digital manufacturing. Siemens claims these solutions rely on the virtual copy or digital twin of physical reality and on the digital thread of this information over the lifecycle and in the extended enterprise (supply chain). Among new technologies enabling digitalization, Siemens claims cyber-physical systems play a central role. In the following, the article expounds vertical integration, end-to-end engineering and horizontal integration as conceived by Siemens. The following are design and planning requirements: vertical integration is a design and planning requirement for cyber-physical systems; end-to-end integration is a design and planning requirement for the processes cyber-physical systems negotiate among themselves; horizontal integration is a design and planning requirement for the entire supply chain. According to Siemens, only a holistic automation approach including the whole value chain will yield sustainable competitiveness, and this holistic solution is Product Lifecycle Management. Vertical integration acts as a design and planning requirement for cyber-physical systems by designing the digital twin of physical devices such as products, production equipment and logistics equipment. This is the system level – systems are modular and autonomous. It is also the first stage of the manufacturing lifecycle in Product Lifecycle Management. This refers to product design, where Siemens claims it is the only company to provide a fully integrated design suite in PLM that offers mechanical, electrical and software design capabilities on a single integrated platform. Cyber-physical systems embed their digital twins. The next level of cyber-physical systems design unites these digital twins in a digital thread. In Industry 4.0 and Siemens' approach to it, this means end-to-end engineering across the value chain. End-to-end engineering plans production processes cyber-physical systems should be capable of and furthermore integrates the product lifecycle. Digital twins of products, production equipment, logistics equipment and the processes they are capable of form a digital thread that moves from one stage of the lifecycle to the next progressively. According to Siemens, the digital thread through the entire value chain means digitalization and is the strategy to realize smart innovation. Digitalization weaves a digital thread through the entire value creation chain. The product lifecycle stages, beginning with product design to service, are digitalized and integrated involving suppliers via the Teamcenter solution in the Digital Enterprise Software Suite. Siemens explains its first step to Industry 4.0 by the digital thread: "Manufacturers must weave a digital thread through ideation, realization and utilization. It is not enough to digitize. That just mimics processes digitally for incremental improvement. You have to digitalize.

proposition for the migration of legacy devices to cyber-physical systems in Industrie 4.0," *Analyzing the Impacts of Industry 4.0 in Modern Business Environments* (Pennsylvania: IGI Global, 2018).

Digitalization makes the digital thread of knowledge a proactive agent in driving your business."

Siemens acknowledges Industry 4.0 as production based on cyber-physical systems. Cyber-physical systems negotiating form Industry 4.0, smart factories as part of the Internet of Things and Services. Horizontal integration is a design and planning requirement for cyber-physical systems on strategy level. Cyber-physical systems function in an integrated supply chain, with new business models and eco-systems. Siemens envisions the emergence of new forms of production in complex networks. In digitalization, networks command. Industry 4.0 is characterized by a leap in complexity compared to previous technology. One form this complexity takes is product variety in mass customization. Siemens argues this business model, which is the most important one in Industry 4.0, can only be achieved in an integrated supply chain. Horizontal integration thereby conditions Industry 4.0. Industry 4.0 processes involve several steps: "step 1, humans conceptualize and design the product"; "step 2, humans determine the production rules and parameters"; "step 3, cyber-physical processes simulates and compares production options on the basis of instructions"; "step 4, cyber-physical processes proposes compliant "optimal" production paths"; "step 5, selection of optimal production path and implementation of production". Integration of product planning and production can reduce time-to-market by 50%. Devices may advance from connected devices to smart automated devices and from there to cyber-physical devices. Siemens identifies three levels where Industry 4.0 will impact production: smart products, with digitalization of product and service offerings; smart factories, which involve digitalization and integration of vertical and horizontal value chains; strategy and innovative business models. Siemens calls the digitalization of the economy the convergence of the cyber world and physical world and the connection of smart factories and smart plants with Internet of Things and the Internet of Services. Cooperation of IIC (Industrial Internet Consortium) and Platform "Industry 4.0" has already started. The classic static production line in manufacturing is being complemented by modular designs. Cyber-physical systems bring flexibility ("maximum structural flexibility and robustness in complex, large-scale distributed systems") and flexibility in time ("via applications, highest functional flexibility and evolution over device and system lifetime"). The supply chain is integrated and able to produce individualized supplies in good quality, at the agreed purchased price, on time, at the requested quantity. The digital factory, also known as Industry 4.0, is a business model for an extended enterprise. Software networks all steps in product development, manufacturing and maintenance. Cyber-physical machines communicate with each other and negotiate processes that optimize manufacturing decisions as a whole. Cyber-physical products communicate with machines their status. Logistics processes are self-organized. The vision can only be achieved if the supply chain is integrated. Siemens intends to develop production networks that are dynamic supply chains and self optimized. Horizontal integration through value networks is a key element of Industry 4.0. Siemens researches how cyber-physical systems can support integrated supply chains and eco-systems of partners that bring new business models.

III. Conclusions

Digital technology may be expressed as IDC's third platform technology, which leads to the digital transformation of organizations, industries, society and to the digital disruption of industries. Among these industries are manufacturing industries, where Industry 4.0 is an alternative name to digital transformation and digital disruption. Industry 4.0 is digital technology in manufacturing, a vision the future of manufacturing industries, an effort shared by governments, research institutes, consultants, manufacturing organizations. Industry 4.0 means manufacturing based on cyber-physical systems negotiating decisions as peers across the Internet of Things and the Internet of Services. There are several stages to Industry 4.0, which may be described by degrees of maturity. Amongst the factors which inflict degrees of digital maturity is technology, the adoption is gradual and begins with connection, the generation of big data to the cloud, the interpretation of this data using analytics technology; the transition to Industry 4.0 involves vertical integration, end to end integration, horizontal integration; the achievement of the full Industry 4.0 vision means manufacturing based on cyber-physical systems in the extended enterprise. Technology generates digital capabilities, such as operational processes, business models, customer experience but the economy is pull, triggered by the customer. The adoption of digital technology is an issue of national and global importance.

IV. Future research directions

According to the Industry 4.0 proposing group, the first examples of the implementation of Industry 4.0 solutions are now available online. The group keeps close watch on Industry 4.0, adept companies, supporting governments and manufacturing organizations. The behaviour of the future Industry 4.0 market may be forecast – for example, as Gartner's hype or similar forecasts. Further research should understand the silent progress towards the vision and the anticipated behaviour of the future market. In touch with the progress of and to the Industry 4.0 market, degrees of maturity may be assessed and created roadmaps towards. The realization of Industry 4.0 can be assessed by maturity scales, which involve the degree of adoption of technology, of business models, of organizations. Maturity scales can be used for individual organizations or for groups of organizations in industries or national economies. One of these national economies is the home of the authors, Romania, and may be the object of an Industry 4.0 adoption maturity assessment for its manufacturing organizations.

References

Accenture. *Are you ready for Digital Industry 4.0?,* 2016. https://www.accenture.com/us-en/insight-digital-industry-solutions?src=SOMS (last time accessed: March 20th, 2017).

Boston Consulting Group. *Industry 4.0: the future of productivity and growth in manufacturing industries,* 2015.

https://www.bcgperspectives.com/content/articles/engineered_products_project_business_industry_40_future_productivity_growth_manufacturing_industries/?chapter=2 (last time accessed: March 20th, 2017).

CapGemeni. *Digital transformation: a roadmap for billion-dollar organizations,* 2011. https://www.capgemini.com/resource-file-ccess/resource/pdf/Digital_Transformation__A_Road-Map_for_Billion-Dollar_Organizations.pdf (last time accessed: March 20th, 2017).

_____. *Crafting a compelling digital customer experience,* 2014. https://www.capgemini.com/resources/digital-transformation-review-6 (last time accessed: March 20th, 2017).

_____. *Industry 4.0 – the CapGemeni consulting view,* 2016. www.de.capgemini-consulting.com/resource-file-access/resource/pdf/capgemini-consulting-industrie-4.0_0.pdf (last time accessed: March 20th, 2017)

Cozmiuc, D., I. Petrişor. "Industrie 4.0 by Siemens - steps made next." *Journal of Cases on Information Technology* 20(1) (2018).

_____. "Industrie 4.0 by Siemens - steps made today." *Journal of Cases on Information Technology* 20(2) (2018).

_____. "Innovation in the age of digital disruption, the case of Siemens." *Strategic Innovation Management for Competitive Advantage.* Pennsylvania: IGI Global, 2018.

_____. "Siemens' customer value proposition for the migration of legacy devices to cyber-physical systems in Industrie 4.0." *Analyzing the Impacts of Industry 4.0 in Modern Business Environments.* Pennsylvania: IGI Global, 2018.

Deloitte. *Industry 4.0 challenges and solutions for the digital transformation and use of exponential technologies,* 2015. https://www2.deloitte.com/content/dam/Deloitte/ch/Documents/manufacturing/ch-en-manufacturing-industry-4-0-24102014.pdf (last time accessed: March 20th, 2017).

_____. *Disruption in manufacturing,* 2016. https://www2.deloitte.com/content/dam/Deloitte/us/Documents/risk/us-risk-disrupt-manufacturing.pdf (last time accessed: March 20th, 2017).

_____. *The smart factory. Responsive, adaptive, connected manufacturing,* 2017. https://dupress.deloitte.com/dup-us-en/focus/industry-4-0/smart-factory-connected-manufacturing.html (last time accessed: March 20th, 2017).

The Digital Manufacturing and Design Innovation Institute. *Join the revolution in American manufacturing*, 2016. http://dmdii.uilabs.org/(last time accessed: March 20th, 2017).

European Parliament. *Industry 4.0 digitalisation for productivity and growth*, 2015. http://www.europarl.europa.eu/RegData/etudes/BRIE/2015/568337/EPRS_BRI(2015)568337_EN.pdf (last time accessed: March 20th, 2017).

_____. *Industry 4.0. Study for the ITRE Committee*, 2016. http://www.europarl.europa.eu/RegData/etudes/STUD/2016/570007/IPOL_STU(2016)570007_EN.pdf (last time accessed: March 20th, 2017).

Gartner. *Cool vendors in digitalization through Industrie 4.0,* 2017,

https://www.gartner.com/doc/3741617/cool-vendors-digitalization-industrie- (last time accessed: May 23rd, 2018).
_____. *Digitalization*, 2017. http://www.gartner.com/it-glossary/digitalization/(last time accessed: May 23rd, 2018).
_____. *Predicts 2017: Industrie 4.0,* 2017. https://www.gartner.com/doc/3571817/predicts--industrie- (last time accessed: May 23rd, 2018).
_____. *Gartner analytics evolution framework*, 2018. https://www.gartner.com/en/documents/3891974 (last time accessed: May 23rd, 2018).
The Global Center for Digital Business Transformation. *Digital vortex*, 2015. http://www.imd.org/dbt/digital-business-transformation/ (last time accessed: March 20th, 2017).
The Global Center for Digital Business Transformation. *Digital business transformation,* 2016. http://www.imd.org/uupload/IMD.WebSite/DBT/Digital%20Business%20Transformation%20Framework.pdf (last time accessed: March 20th, 2017).
_____. *Digital vortex. How digital disruption is redefining industries,* 2016. http://www.imd.org/uupload/IMD.WebSite/DBT/Digital_Vortex_06182015.pdf (last time accessed: March 20th, 2017).
Grossman, R. (2016), The Industries that are being disrupted the most by digital, *Harvard Business Review,* March 2016.
Hermann, M., Pentek, T., and Otto, B. (2014), *Design principles for Industrie 4.0 scenarios: a literature review, http://www.thiagobranquinho.com/wp-content/uploads/2016/11/Design-Principles-for-Industrie-4_0-Scenarios.pdf* (last time accessed: March 20th, 2017).
IBM Institute for Business Value. *Digital transformation. Creating new business models where digital meets physical*, 2011. https://www-935.ibm.com/services/in/gbs/thoughtleadership/ibv-digital-transformation.html (last time accessed: March 20th, 2017).
_____. *Digital transformation*, 2016. http://www-01.ibm.com/common/ssi/cgibin/ssialias?infotype=PM&subtype=XB&appname=GBSE_GB_TI_USEN&htmlfid=GBE03399USEN&attachment=GBE03399USEN.PDF (last time accessed: March 20th, 2017).
IDC. *Explore 3rd platform transformation*, 2017. http://www.idc.com/promo/thirdplatform (last time accessed: May 23rd, 2018).
Kagermann, H. *Recommendations for implementing the strategic initiative Industrie 4.0: Final report of the Industrie 4.0 Working Group*, 2013. http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report__Industrie_4.0_accessible.pdf (last time accessed: March 20th, 2017).
KPMG. *The fourth industrial revolution. How does the factory of tomorrow look like?,* 2015. https://www.kpmg.com/TR/en/hizmetlerimiz/Advisory/management-consulting/Documents/industry-4.pdf (last time accessed: March 20th, 2017).

Kumari, M. M.S. Kulkarni. "A complexity based look-ahead mechanism for shop floor decision making." *Procedia CIRP* 41 (2016): 63 – 68.

Lee, J., Bagheri, B., and Kao, H. (2015), A Cyber-Physical Systems architecture for Industry 4.0 based manufacturing, *Manufacturing Letters*, *3*, 18–23

Markets and Markets. *Industry 4.0 market worth 152.31 billion USD by 2022*, 2017. http://www.marketsandmarkets.com/PressReleases/industry-4.asp (last time accessed: May 23rd, 2018).

Oracle. *Oracle Enterprise Product Lifecycle Management*, 2012. http://www.oracle.com/us/products/applications/agile/enterp-prod-lifecycle-manag-rept-1621419.pdf (last time accessed: March 20th, 2017).

Petrişor, I., D. Cozmiuc. "Global supply chain management organization at Siemens in the advent of Industry 4.0." *Global Intermediation and Logistics Service Providers*. Pennsylvania: IGI Global, 2012.

Plattform Industrie 4.0, *Plattform Industrie 4.0, 2014: Industrie 4.0. Whitepaper FuEThemen,* 2014. http://www.plattformi40.de/sites/default/files/Whitepaper_Forschung%20Stand%203.%20April%202014_0.pdf (last time accessed: March 20th, 2017).

PriceWaterhouse Coopers. *Industry 4.0: building the digital enterprise*, 2016. https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digitalenterprise-april-2016.pdf (last time accessed: March 20th, 2017).

Roland Berger Consultants. *Industry 4.0: a real quantum leap*, 2015. https://www.rolandberger.com/en/Blog/Industry-4.0-quantum-leap.html (last time accessed: March 20th, 2017).

Toro, C., I. Barandiaran, J. Posada. "A perspective on Knowledge Based and Intelligent systems implementation in Industrie 4.0." *Procedia Computer Science* 60 (2015).

Van Alstyne, M. W., G.G. Parker, S.P. Choudary. "Pipelines, platforms, and the new rules of strategy." *Harvard Business Review* (2016).

Veza, I., M. Mladineo, N. Gjeldum. "Managing Innovative Production Network of Smart Factories." *IFAC-PapersOnLine*, 48(3) (2015).

Westerman, G., D. Bonnet, A. McAfee. "Digital Transformation: A Roadmap for Billion-Dollar Organizations." Harvard Business Review Press (2014).

_____. "Leading Digital. Turning Technology into Business Transformation." *Harvard Business Review Press* (2014).

World Economic Forum. *Digital disruption has only just begun*, 2016. https://www.weforum.org/agenda/2016/01/digital-disruption-has-only-just-begun/(last time accessed: March 20th, 2017).

_____. *Digital Transformation of Industries*, 2016. http://reports.weforum.org/digital-transformation/wpcontent/blogs.dir/94/mp/files/pages/files/digital-enterprisenarrative-final-january-2016.pdf (last time accessed: March 20th, 2017).