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Digitalization – Developing Design and Implementation Theory

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Digitalization
– Developing Design and Implementation Theory –

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Background

Little did we know of all the changes the world would go through, when we issued the call for papers for a special issue on Digitalization – Developing Design and Implementation Theory, back in Fall 2018.

Bad things happened. The COVID-19 pandemic has already taken nearly 2.2 million lives[1], collateral deaths not included, and is still raging. The climate crisis seems to accelerate with enormous bush fires in Australia, California and Siberia, a further increase of greenhouse gas emissions in 2020, one of the hottest years ever, in spite of much reduced travelling and industrial production[2].

Fortunately also many good things happened. The USA decided to rejoin the Paris Climate Agreement. Brexit happened, for better or for worse, but the good news is that partners managed to land an agreement. And there are many, many examples of social innovations and human ingenuity.

In industry, pharmaceutical firms developed at "warp speed" over 50 COVID-19 vaccine candidates to trialability[3], and just before the end of 2020, the first people were vaccinated. Worldwide, companies, small and large, showed unprecedented agility. On April 13, 2020, Lego, the children's toys brand reported that they had modified six of its molding machines to produce more than 13,000 visors per day for frontline healthcare workers. Similar plans were in place for Hungary and then Lego's other global plants[4]. Grundfos, the pump manufacturer, started full-scale production of up to 5000 visors per day in Bjerringbro, Denmark, on April 3, 2020[5]. Carlsberg restructured a large part of its production in Fredericia, Denmark, to supply the alcohol base to former demonstration plant of Ørsted, a renewable energy company[6], in Kalundborg, Denmark, for second-generation bioethanol production.

1 Johns Hopkins University, Center for Systems Science and Engineering (CSSE), https://gisanddata.maps.arcgis.com/apps/opsdashboard/index.html#/bda7594740fd40299423467b48e9ecf6, accessed on 28 January 2021.

2 World Meteorological Organization, https://public.wmo.int/en/our-mandate/climate/wmo-statement-state-of-global-climate, accessed on 26 January 2021.

3 World Health Organization, https://www.who.int/emergencies/diseases/novel-coronavirus-2019/covid-19-vaccines, accessed on 26 January 2021.

4 https://www.plasteurope.com/news/LEGO_t244935/, accessed on 27 January 2021.

5 https://www.grundfos.com/about-us/news-and-media/news/grundfos-ready-to-support-healthcare-system0, accessed on 28 January 2021.

6 https://orsted.com/en/about-us, accessed on 28 January 2021.

Ten tankers operating 24 hours a day supply 1.4 million liters of alcohol base per week to keep the plant running. The first tankers were dispatched April 9, 2020[7]. Project Pitlane, a collective of seven UK-based Formula 1 teams, their respective technology arms and Formula One, announced that they will pool the resources and capabilities of its member teams to greatest effect, focusing on the core skills of the Formula One industry: rapid design, prototype manufacture, test and skilled assembly, to reverse engineer existing medical devices, support in scaling the production of existing ventilator designs, and prototype manufacture of a new device for certification and subsequent production[8]. One example concerns the UCL[9]-Ventura breathing aid, a Continuous Positive Airway Pressure (CPAP) device, which helps COVID-19 patients to breathe when an oxygen mask is insufficient. On March 29, 2020, the Mercedes-AMG Petronas Formula One Team reported that engineers at UCL and Mercedes-AMG High Performance Powertrains (HPP), where all operations associated with Mercedes' Formula One Powertrains are centralized, worked round-the-clock to reverse-engineer a device that to be produced at a rate of up to 1,000 a day at the HPP technology center in Brixworth, United Kingdom, using 40 machines that would normally produce F1 pistons and turbochargers. On March 24, 2020, Reuters reported that Ford joined forces with General Electric and 3M in Project Apollo to produce ventilators supporting patients with respiratory failure or difficulty breathing and more than 100,000 full-face shields a week at non-vehicle manufacturing facilities in Michigan, USA, using 3D printers[10].

The latter brings us to the focus of this special issue. In our call for papers, we referred to the enormous progress made in the last four centuries, in product and process technologies, markets and competition, economic systems and societies:

1. The first industrial revolution, which took place from the 17th into the 19th century, witnessed the invention of the steam engine, which enabled the centralization of work in factories, and turned largely rural societies into today's industrial societies.
2. The second industrial revolution, which started towards the end of the 19th century, revolved around the emergence of Fordist mass production and the "invention" of capitalism as the dominant economic system.
3. The third industrial revolution, also called the digital revolution, which was triggered by the invention of the computer in the 1940s and the further development of information and communication technology, saw the development and spread of minicomputers and DNC, followed by first industrial robots, CNC machine tools, and FMSs in production industries, desktops and, later, laptops becoming affordable for use in offices and at home, and the invention of the internet protocol enabling the massive growth of the internet in the form of, amongst others, e-business.

Today, we are at the brink of the fourth industrial revolution. Technologies and concepts enabling this latest stage of development include artificial intelligence, robotics, nanotechnology, additive technologies such as 3D printing, big data analytics, and the internet of things and services (IoT/S).

Digitalization opens up for promising opportunities but managing its implications for product, process, job, organization and supply network design and implementation is potentially immensely complex.

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7 https://novonordiskfonden.dk/en/news/emergency-production-of-ethanol-to-contribute-to-combating-virus-transmission/, accessed on 28 January 2021.

8 https://www.formula1.com/en/latest/article.uk-based-f1-teams-unite-around-project-pitlane-to-assist-with-ventilator.7G8gQu9v8j6aSgqk3P52fp.html, accessed on 28 January 2021

9 University College London.

10 https://www.reuters.com/article/us-health-coronavirus-ford-motor-idUSKBN21B1PD.

Various state-of-the-art studies[11] have been reported together with case examples of smart factories, including Siemens' Electronic Works facility, Amberg, Germany[12], BASF's pilot plant at the German Research Center for Artificial Intelligence, Kaiserslautern[13], Robert Bosch GmbH's smart factories in Blaichach and Homburg, Germany[14]; and Audi's A4*/A5*/Q5 assembly facility, Ingolstadt, Germany, a "networked digital factory"[15]. What is lacking so far is the rigorous development of robust theory as we saw it during the first phase of digitalization in the 1980s and 1990s.

The papers

This special issue contains twelve papers, each of which contributes to the development of digitalization theory. Ten papers are based on empirical research – three survey-based and seven single, multiple or embedded case studies; two papers are based on literature reviews. Ten papers focus on manufacturing operations, one on predictive condition-based maintenance, one of physical-digital product development. Three of the papers focus on the implementation of digitalization.

Industry 4.0 and lean manufacturing: A systematic literature review and future research directions from Marcos Pagliosa, Guilherme Tortorella and Joao Carlos Espindola Ferreira aims to identify the relationships between Industry 4.0 technologies and Lean Manufacturing practices. The authors perform a systematic literature review in which 93 studies are analyzed. They identify nine Industry 4.0 technologies and fourteen Lean Manufacturing practices which they categorize according to different levels of both value stream application and synergy. From the 126 pairwise relationships, 24 are classified as being of high synergy (e.g. relationship between Cyber-Physical Systems and value stream mapping), revealing the existence of a positive interaction between Lean Manufacturing practices and Industry 4.0 technologies toward the achievement of a higher operational performance. Further, three future research opportunities were suggested: (1) to validate the proposed synergies among Lean Manufacturing practices and Industry 4.0 technologies, (2) to distinguish the effects of relationships on all levels of flow, and (3) to examine the effect of such relationships on operational performance.

Cristina Orsolin Klingenberg, Marco Antônio Viana Borges and José Antônio Valle Antunes Jr. authored *Industry 4.0 as a data-driven paradigm: A systematic literature review on technologies*. Aimed at identifying current technologies related to Industry 4.0 and developing a rationale to enhance the understanding of their functions within a data-driven paradigm, the authors perform a systematic literature review of 119 papers published in journals to identify Industry 4.0 technologies. Their analysis identified 111 technologies, which perform four functions related to data: data generation and capture, data transmission, data conditioning, storage and processing and data application. The

[11] Deloitte (2015). Industry 4.0. Challenges and Solutions for the Digital Transformation and Use of Exponential Technologies. Zürich: PwC (2015). Industry 4.0: Building the digital enterprise. http://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digital-enterprise-april-2016.pdf, retrieved on 11 February 2018.

[12] Alessi, C. and Gummer, C. (2014). Germany bets on 'smart factories' to keep its manufacturing edge. *The Wall Street Journal*, October 26; Hessman, T. (2013). The dawn of the smart factory. *Business Week*, 14 February: 15-19.

[13] Alessi, C. (2014). Germany develops 'smart factories' to keep an edge. *MarketWatch*, 27 October; https://www.marketwatch.com/story/germany-develops-smart-factories-to-keep-an-edge-2014-10-27, retrieved on 28 January 2021.

[14] https://www.bosch.com/stories/the-connected-factory/; https://www.bosch.com/stories/new-approaches-to-manufacturing/, both accessed on 28 January 2021.

[15] Audi_in_Ingolstadt_2020_EN_final.pfd, retrieved on 28 January 2021.

first three groups consist of enabling technologies and the fourth group of value-creating technologies. The results show that Industry 4.0 publications focus on enabling technologies that transmit and process data. Value-creating technologies, which apply data in order to develop new solutions, are still rare in the literature.

Guilherme Tortorella, Rapinder Sawhney, Daniel Jurburg, Istefani Carisio de Paula, Diego Tlapa and Matthias Thurer pursue two objectives in their paper *Towards the proposition of a lean automation framework: integrating Industry 4.0 into lean production*. First, they aim at identifying the pairwise relationships between Lean Production practices and Industry 4.0 technologies. Second, based on these results, they propose a framework for Lean Automation implementation, in which Industry 4.0 technologies are integrated into Lean Production practices. The authors perform a cross-sector survey with 147 manufacturers that implemented Lean Production aided by Industry 4.0 information and communication technologies. They find that Industry 4.0 technologies are positively correlated with Lean Production practices, providing evidence to bear the proposition of a Lean Automation framework that can potentially overcome traditional barriers and challenges associated with the implementation of Lean Production.

Sven-Vegard Buer, Jo Wessel Strandhagen, Marco Semini and Jan Ola Strandhagen aim at developing digitalization contingency theory. In their paper on *The digitalization of manufacturing: Investigating the impact of production environment and company size*, they observe that, while manufacturing digitalization is currently considered an important enabler of competitive advantage, its applicability across the industrial spectrum is unclear. The authors aim to investigate the relationship between the use of digital technologies and different production environments and company sizes. The focus is on three aspects of digitalization: shop floor digitalization, technologies for vertical and horizontal integration and organizational IT competence. Based on data gathered from a survey questionnaire sent to 212 Norwegian manufacturing companies and analyzed using two-way analysis of variance (ANOVA), the study confirms that large enterprises have a significantly higher level of shop floor digitalization and organizational IT competence than small and medium-sized enterprises. Regarding the difference between production environments, they find no statistically significant difference in the implementation level of the investigated digitalization aspects.

Captive offshoring, offshore outsourcing and re-, back- and nearshoring are important empirical phenomena. *Cost-driven motives to relocate manufacturing abroad among small and medium-sized manufacturers: The influence of Industry 4.0*, from Jan Stentoft, Kent Adsbøll Wickstrøm, Anders Haug and Kristian Philipsen, aims to advance the understanding of how Industry 4.0 related technologies affect the relocation of manufacturing abroad by small and medium-sized enterprises. The authors perform an empirical analysis of how Industry 4.0 related technologies affect the cost-driven relocation of manufacturing abroad based on 191 comprehensive and full responses to a questionnaire survey distributed in 2018 among small- and medium-sized Danish manufacturers. The data reveal that companies' pursuit of cost-focused competitive strategies is positively correlated with relocating manufacturing abroad, but also show that the more Industry 4.0-ready decision-makers are, the less cost-focused strategy drives manufacturing abroad. Furthermore, perceived barriers to Industry 4.0 related technologies promote the cost-driven relocation of manufacturing abroad whereas perceived drivers decrease this phenomenon.

Buer *et al.* (firm size, production environment) and, in some way, also Stentoft *et al.* (strategy) look into the influence of contingency factors, Levente Szász, Krisztina Demeter, Béla-Gergely Rácz and

Dávid Losonci follow suit and investigate the performance effects of Industry 4.0 in addition. Their paper, *Industry 4.0: A review and analysis of contingency and performance effects* reviews the literature on, and offers a more generalizable empirical investigation of, the performance impact of implementing Industry 4.0, and the way important contingency factors (plant size, multinational status, country context) affect implementation efforts. Following a systematic literature review, the empirical research is based on a large-scale survey of 705 manufacturing plants from 22 countries. Structural equation modeling is employed to discover the relationships between the main constructs of interest, complemented with subgroup analyses to offer a more detailed understanding of the main effects. The authors provide evidence that technologies enabling Industry 4.0 have a positive impact on operational performance, including cost, quality, delivery and flexibility performance. Results of the analyses further indicate that (1) larger firms invest more in implementing Industry 4.0 technologies, (2) manufacturing firms in less competitive countries, especially in the South-East Asian region invest significantly more effort than competitive countries, while (3) multinational companies have no advantage over local firms.

Essentially aiming at the development of contingency theory, too, Chiara Cimini, Albachiara Boffelli, Alexandra Lagorio, Matteo Kalchschmidt and Roberto Pinto aim to investigate the organizational perquisites for, and consequences of, adopting Industry 4.0 technologies, giving specific attention to operations. Their paper *How do Industry 4.0 technologies influence the organization? An empirical analysis on Italian SMEs* is based on a ten case studies of Italian small and medium enterprises (SMEs) in manufacturing. The results show that: (1) a lean organizational structure supports effective adoption of Industry 4.0 technologies, (2) introducing such technologies is linked to developing a new kind of job profile (i.e. the "Autonomous Operative Job Profile"), and (3) higher levels of technology adoption create a higher need for non-technical competences.

Whereas the majority of papers in this special issue focus on manufacturing operations, two papers address non-manufacturing processes. *Condition-Based Maintenance for Major Airport Baggage Systems* takes us to maintenance operations at airport. Frank Koenig, Pauline Anne Found, Maneesh Kumar and Nicholas Rich seek to develop empirically based evidence of predictive condition-based maintenance by demonstrating how the availability and reliability of current assets can be improved without costly capital investment, resulting in overall system performance improvements. The experimental approach, technical action research (TAR), was designed to study a major Middle Eastern airport baggage handling operation. A predictive condition-based maintenance prototype station was installed to monitor the condition of a highly complex system of static and moving assets. The research provides evidence that the performance frontier for airport baggage handling systems can be improved using automated dynamic monitoring of the vibration and digital image data on baggage trays as they pass a service station. The introduction of low-end innovation, which combines advanced technology and low-cost hardware, reduced asset failures in this complex, high-speed operating environment.

Exploring coordination practices in digital–physical product development from Stine Hendler is the second, non-manufacturing focused paper in this special issue. The paper explores coordination practices in digital-physical product development and their consequences for companies traditionally relying on physical product development. Using an embedded case study design, the paper reports four action research initiatives addressing the digital-physical coordination challenges encountered by a leading B2C company. The study suggests that effective coordination of digital-physical product development, firstly, involves standardization of process, output and skills to accommodate the stability needed for efficient physical product development and manufacturing. Secondly, it involves agile coordination events, such as Scrum ceremonies and PI planning, to facilitate the mutual adjustment needed to allow agility and the differences between digital and physical product development to be continuously and successfully negotiated.

The last three papers in this special address the implementation of digital technologies. Sara Johansson, Malin Kullström, Jennie Björk, Anna Karlsson and Susanne Nilsson take us to *Digital production innovation projects – The applicability of managerial controls under high levels of complexity and uncertainty*. The purpose of their study is to assist academics and practitioners in supporting and managing digital production innovation projects using managerial controls. The focus is on projects that deliver innovations containing new combinations of physical, digital and/or cyber-physical components, developed to be used within a production system. Based on five digital production innovation projects in two manufacturing firms, the paper explores the applicability of different managerial controls for managing and supporting digital production innovation projects, i.e. projects that are characterized by high levels of complexity and uncertainty. The empirical data was used to analyze success factors, challenges and obstacles in different phases of the studied projects, and to connect these to the application of different types of managerial controls. The findings reported in the paper provide an increased understanding of who to control, what to control and how to control in digital production innovation projects. Given the necessary system perspective on managerial controls that is being highlighted, this paper emphasizes further research needs on how firms can also apply managerial controls to support external collaborations.

The second implementation focused paper *What matters in implementing the Factory of the Future: Insights from a survey in manufacturing* is from Elena Pessot, Andrea Zangiacomi, Cinzia Battistella, Valerie Rocchi, Alessandro Sala and Marco Sacco. This paper aims to study the extent of the transformation of European manufacturing companies towards the Factory of the Future and related concepts, e.g. Industry 4.0 and digitalization. The authors use a qualitative survey design to investigate the areas, patterns and elements for implementing the Factory of the Future. A total of 92 responses from manufacturing firms of Alpine regions of Austria, France, Germany, Italy and Slovenia were collected and analyzed, followed by in-depth interviews with a subset of respondents to identify common challenges, drivers and opportunities for the transformation. They observe that manufacturing companies are gaining awareness on their needs and gaps in the Factory of the Future path, the implications on business strategy and the rates of innovation and technology adoption. Nevertheless, they still need to shape their organizational structures (e.g. from highly centralized to more collaborative ones) and nurture their managerial capabilities in operations and supply chain management, and customer relationships, only partially based on Factory of the Future technologies.

Last but not least, *Road to digital manufacturing – A longitudinal case-based analysis* from Krisztina Demeter, Dávid Losonci and Judit Nagy aims to examine how and why a factory adapts its resources and capabilities during digital transformation. To grasp the change, the authors apply the longitudinal case study method within a revelatory case setting. The digital transformation is detailed from the perspective of a subsidiary that has played a key role in the division's digital transformation. Analyzing the revealed four stages of the transformation through the lenses of the dynamic capability components of adaptation (sensing capability, absorptive capacity, integrative capability, relational capability), this study suggests a sequence with unbalanced characteristics. Each stage starts with sensing capability, each component appears during each stage and each stage is dominated by a different component. Relying on the path dependency concept, the authors also present that the interplay between lean as an old resource stock and digital manufacturing as a new resource stock is rather a necessity, especially at the beginning of the transformation at a company that had pursued lean for years.

Finally, we wish to thank the authors whose papers ended up in this special issue, the authors who we had to disappoint, the numerous reviewers who helped us going through up to four versions of the manuscripts, and last but not least editorial team of the Journal of Manufacturing Technology for their trust, support and patience throughout the development of this special issue.

The guest editors.