Editorial

Smart production: towards an action and design science research approach

Introduction

In the last decade, manufacturing industries across the globe have undergone a significant transformation. From considering manufacturing an inferior activity, best approached by outsourcing and offshoring to low-cost countries, manufacturing has moved to the top of the strategic agenda. In a general perspective, what we have seen is a shift from globalization toward reindustrialization, and all economies around the globe are embarking on the same journey. Going through what has been termed the *Fourth Industrial Revolution* (Industry 4.0), most societies and economies around the world are facing an increasingly rapid digital transformation of trade, industry and society itself. As the now commonly used word "transformation" suggests, there is a consensus around the magnitude of change that has already started and that will affect all aspects of our society in the not-so-distant future. Though, a shared understanding of the details around what such change actually entails and a shared vision for the future of industries, education systems and the organization of societies has not yet emerged. The essence of the transformation was captured by the German high-tech strategy project called "Industrie 4.0" (Kagermann *et al.*, 2013) presented at the Hannover Fair in 2011, and it was later adopted by the World Economic Forum and promoted as the convergence of physical, digital and biological activities driving transformation in the society in general (Schwab, 2016). In recent years, we have seen how the emerging concept of Industry 4.0 has challenged manufacturing companies to digitalize and automate, leading to the need for also reorganizing work and competences to capture the potential benefit.

Industry 4.0 is now the overarching theme of a large number of global national initiatives such as, to mention but a few, Smart Manufacturing (USA), Factory of the Future (EU), Catapult (UK), Smart Industries (NL), Production 2030 (SE), Made in China 2025 (CN), Make in India (IN) and Manufacturing Academy of Denmark (DK). They all share the focus on Industry 4.0 technologies as enablers of manufacturing digitalization and automation (Xu *et al.*, 2018).

The digital transformation and new business models enabled by emerging technologies may be the key to increase productivity and growth and create a basis for our shared future prosperity[1]. The complexity of and speed at which new technology–enabled business and operations models are emerging are creating several valuable lessons while at the same time posing new research questions that need to be further investigated. At the same time, the distributed nature of today's global knowledge creation, means that it is ever more important to create opportunities to share widely such lessons and learn globally from local experience.

It is exactly with this in mind that we have created this special issue of the *Journal of Global Operations and Strategic Sourcing*, aiming to investigate the broad theme of "Smart Production and Industry 4.0" by presenting and disseminating "current and future design science–based research supporting the Danish Manufacturing Industry."

In this special issue, we have collected insights particularly on the Industry 4.0 transformation as it has played out in the context of Danish industry. It is arguably a somewhat unusual choice to frame an entire special issue around a particular national context. However, this particular context provides a highly interesting test-setting for further understanding the mechanisms of the transformation toward Industry 4.0. The Danish society is by the Digital Economy and Society Index (European Commission, 2021) ranked as the third most digital country in Europe (measured across the dimensions of

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connectivity, human capital, use of internet services, integration of digital technology and digital public services). Furthermore, Danish manufacturing industry is characterized by a set of particular contingencies (e.g. low volume/high mix, high skill, low tech and high cost). The combination of a high general societal digitalization level, and a manufacturing landscapes which calls for significant changeability and flexibility to stay competitive, provides an empirical context in which we can clearly identify both problems and opportunities related to digital transformation. Recognizing the undeniable opportunities created by emerging technologies, the Danish Government has defined a vision "for Denmark to be a digital frontrunner, with all Danes gaining from the digitalization" and presented its "Strategy for Denmark's Digital Growth," in which it sets the direction as to how Denmark can seize the opportunities inherent in digital transformation, while creating jobs and improving growth and prosperity in Denmark.

More specifically, this SI reports on the latest activities and lessons learned from several research projects undergoing at the University of Aalborg (AAU), Faculty of Engineering and Science, Department of Materials and Production, under the Manufacturing of Denmark Academy program. AAU has recently risen from No. 18 to an impressive eighth place among the world's top universities for engineering. In this leap, AAU has overtaken both Stanford University and Georgia Tech. This ranks AAU as the best European university for engineering"[2]. Hence, the presentation and discussion of the work currently shaping the future of the Danish manufacturing industry is inevitably going to offer insight that is both relevant and transferrable to manufacturing sectors in other regions, where the emergent paradigm of smart and digital production systems, also commonly referred to more broadly as Industry 4.0, is being studied and experimented with.

Digitalization of manufacturing poses interesting questions for how we perform research on operations management. Operations management is widely considered as a problem-solving discipline, seeking to create knowledge by interacting with the real world (McCutcheon and Meredith, 1993; Lewis, 1998). As new Industry 4.0 solutions reach beyond mere technology implementation, operations management researchers also need to engage more deeply with industrial organizations to understand those issues and contingencies that affect the design, or anyway the execution, of those organizations' digital transformation journey.

Design or action sciences in operations (Holmström *et al.*, 2019) respond exactly to this need. Inspired by Herbert Simon (1996), design or action sciences are conceptualized as a set of research strategies aimed at creating knowledge that can be used in an instrumental way to design and implement actions, processes or systems to achieve desired outcomes in practice. According to Aken *et al.* (2016) design science research is conducted under many different labels: action science, action research, participatory action research, participatory case study, etc. The common goal in all these endeavors is the same: the researcher is interested in developing "a means to an end," an artifact to solve a problem. Design science is thereby fundamentally different from both the theory-building and -testing approaches. Design science is research that seeks:

- to explore new solution alternatives to solve problems;
- to explain this explorative process; and
- to improve the problem-solving process.

As such, the approach is driven by field problems or opportunities; instrumental knowledge is developed by deep engagement with these real-life problems or opportunities, and the core research products are well-tested, well-understood and well-documented innovative generic results (designs).

In this special issue, we have responded to the need to further discuss and explore the changing manufacturing agenda in Denmark in light of the abovementioned development. The special issue: "Smart Production and Industry 4.0: current and future design-science research supporting the Manufacturing Industry" is as such the first of its kind, as it aims to investigate the broad themes of smart production and Industry 4.0. by focusing in particular on design science–based research of experimental nature.

Contributions of this special issue

This special issue presents four papers, which form a mosaic of the research approaches applied in research on Industry 4.0 over the past few years. The research is based in industrial sponsored projects and tackling challenges faced by the Danish manufacturing industry. The four cases share the characteristics of starting with a new problem in one or more companies leading to formulating a generalized problem and ending with a solution that may be transferrable to industry in general.

In the first paper, "Determining manufacturing system changes based on new product specifications," the authors propose a combined product and production modeling approach enabled by digital manufacturing. The authors investigate how necessary changes in a manufacturing system can be determined based on a new product specification. A formal modelling approach is proposed, enhancing the utilization of changeability of a manufacturing system. The approach was developed in the AAU Smart Production Laboratory, which is an Industry 4.0 small-scale environment used for experimentation with new smart production concepts. The problem was generalized from observations in several past research projects on designing smart factories, simplified and brought into the lab. The paper demonstrates a core process in design-oriented industrial research: generalizing a problem and transferring it to a controlled environment and developing a specific artifact to be proposed as a general solution.

In the second paper, "Building a Virtual Factory: An Integrated Design Approach to Building Smart Factories," the authors present the design of a complete virtualized factory environment based on a digital twin, which is used by a large manufacturer to reduce time to market. The paper demonstrates the design of an experimental artifact used inside the company to explore the potential benefits from using a live model of the manufacturing system constraints to align the stakeholders involved in producing a capital goods product. Starting from the proposed highly context-specific artifact, the authors discuss how the same benefits could be gained in similar manufacturing contexts. This paper demonstrates another important process in design-oriented industrial research, where a potential general solution is tested in different contexts to increase robustness and to understand contingencies.

The third paper, "The influence of new technologies on coordination strategies," deals with the strategic repositioning of an engineer-to-order (ETO) sub-supplier, enabled by inter-operational business intelligence in the configuration processes. In this paper, the authors find that inter-operational business intelligence across configuration processes allows for a replenishment lead time in an ETO company relatively like that of an assembly-to-order. This research is based on several research projects in the specific case company, and the proposed solution is highly context specific, but the coordination mechanisms are generalized and suggested to be identical in any ETO company in a similar supply chain structure. In this paper, it is demonstrated how particular and partial solutions may be aggregated into an overall solution that is seen as a particular example of a generalized solution.

The final paper, "Labour 4.0: Developing competences for Smart Production", presents a study on how companies develop and acquire competences to capture the benefits of Industry 4.0 technologies. The paper is based on a process study of 33 small- and medium-sized companies engaged in the manufacturing industry transformation from different

perspectives as either manufacturers or manufacturing solution providers. The conclusions are drawn from a Danish population of companies in the manufacturing industry and are as such based on particular contingencies (e.g. low volume/high mix, high skill, low tech and high cost). However, the findings are believed to be applicable across different sets of contingencies where the need to combine legacy and emerging technologies is present and where the human factor is central to leverage technology beyond predefined supplier specifications. The authors argue that this is a fundamental and often overlooked prerequisite for industrial transformation.

Studying and researching digital transformation of the manufacturing industry is challenging as the transformation transcends particular technologies, organizational boundaries, systems and different business models. This implies the need to engage closely with industry and study not only the digital artifact but also to understand the business and organizational context in a longitudinal perspective.

The four articles in this special issue contains a mosaic of such studies. However, they share a common approach to design-oriented industrial research. Each of the papers presents interesting findings on their own merits, but in combination, the four contributions also provide a valuable insight into an emerging design- and action-driven approach to research in operations management. Across the four papers, it becomes evident that the particular context of the Danish manufacturing industry unveils industrial characteristics, which is highly valuable for developing, testing and implementing design and action driven research on Industry 4.0. The characteristics which favor this approach are, e.g. the close collaboration between university and industry; a problem-based approach to scoping relevant research topics; a highly iterative and experimental approach to knowledge development, which allows for continuous knowledge production in practice; and a highly base-level of digitalization, which allows for experiments on Industry 4.0 that create results, which are on the forefront of research on Industry 4.0.

With an outset in actual specific problems and opportunities, and with the aim to develop instrumental knowledge with practical as well as academic relevance, the papers demonstrate research based on a problem-based approach to designing new solutions. Industry 4.0 is seen a context in which new digital smart production solutions emerges rapidly, which prompts for an industrial research approach that is able to capture, formulate and generalize new knowledge at a much higher speed than classical research. This again requires that industry and academia engage closely and collaborate on more experimental solutions, where the outcomes are less substantiated, but the potential gains are higher.

Obviously, the Danish context favors this, but in most European countries, these conditions would be similar, and therefore, the design-oriented approached should be attempted. Industry 4.0 presents industry with so many new opportunities that needs to be explored but also well know issues that we already have available solutions. And the two perspectives need to be combined. Enjoy the papers.

Astrid Heideman Lassen
Department of Materials and Production, Aalborg University, Copenhagen, Denmark, and
Charles Møller
Materials and Production, Aalborg University, Copenhagen, Denmark

Notes

1. Strategy for Denmark's Digital Growth, Ministry of Industry, Business and Financial Affairs.
2. www.eciu.org/news/aau-is-the-best-european-university-for-engineering, visited on September 15, 2018.

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Further reading

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