Digitalization in Manufacturing: Trends, Drivers, Challenges, and Research Areas in Norway

Emrah Arica, Daryl Powell

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Emrah Arica[1] and Daryl Powell[2]

SINTEF Manufacturing, Horten, Norway
{emrah.arica, daryl.powell}@sintef.no

Abstract. The manufacturing industry has encountered a need for digital transformation during the past decade. To stay competitive, more and more manufacturing companies are adopting digital technologies, either by internal efforts or through external help from consultants or collaborative research projects. This paper presents an overview of trends and challenges in the Norwegian industry and provides a framework of critical research areas for further efforts in the digitalization of manufacturing. The framework is developed based on an analysis of six exemplary industrial research projects that focus on the subject of digitalization in manufacturing. The paper contributes to the literature by bringing practical insights that guide the digital transformation of manufacturing companies.

Keywords: Digitalization, Manufacturing, Industry 4.0

1 Introduction

The manufacturing industry is transforming to the Industry 4.0 era characterized by a high degree of automation and continuous data exchange in production, through the utilization of new digital solutions (eg Sensorics, Augmented Reality, and industrial internet) and methodologies (eg Big Data Analytics) [1].

With the primary focus on knowledge-driven, complex, and technologically advanced products and services, Norwegian manufacturers' competitiveness and growth depend largely on the utilization of new digitalization technologies to achieve higher productivity as a high-cost country. Norwegian SMEs are especially challenged by investing in potentially capital-intensive systems and technologies, which makes research-driven innovation projects an essential driver of digital transformation.

This paper draws the digital transformation trends, drivers, and challenges in the Norwegian manufacturing industry, extracted from the industry-driven research projects conducted and coordinated by the SINTEF research center. Six exemplifying research project cases are analyzed and discussed. While existing frameworks point out the potential applications and benefits of enabling technologies, studies on industrial application areas and implementation efforts are still scarce. The paper contributes to the literature by providing insights on the digitalization projects of manufacturing companies, as well as illustrates their requirements to guide further research activities.

2 Digitalization in Manufacturing

With the increasing industrial interest in Industry 4.0, researchers and policymakers have developed frameworks to define and characterize this emerging concept, and guide the industries in the digital transformation processes. The research work for guiding digital transformation in manufacturing can be categorized into three aspects: *application areas, enabling technologies, reference frameworks*.

Application areas of digitalization in manufacturing are growing with industrial interests. Some examples of the application areas are the following: (i) managing the material flows and production logistics more efficiently by for example implementing a cyber physical logistics system to increase the Kanban system with many variants of products [1]. (ii) enhancing the operator work, training, and their interaction with the systems by for example implementing Augmented Reality for work instructions and accelerating operator learning [2]. (iii) new business models and product services supported by digital technologies such as adopting a service platform that leverages the value of smart and connected resources for advanced service offerings (e.g. productivity improvement offering based on risk and reward sharing) [3]. (iv) sustainable manufacturing enhanced by new digital technologies such as developing a digital platform enabling a marketplace for sharing unused manufacturing capacities (e.g. materials, resources, technologies, and byproducts) [4].

Enabling technologies incorporate various technologies, including but not limited to sensors, robotics/automation, big data analytics, augmented reality to realize the vision of a data-driven, connected supply network, and to improve manufacturing operations at all levels (i.e. shop floor, factory, supply chain) of the supply network [1].

Reference frameworks aim to match the requirements of the companies with the application of enabling technologies and to guide them in the digital transformation process. The reference frameworks help companies at different levels, including but not limited to: (i) building a digitalization strategy aligned with the business and corporate strategies, and supporting the long-term digitalization transformation [5]. (ii) assessing the current digital maturity of a company, identifying the development requirements, and outlining the opportunities and constraints by digital maturity assessment tools [6]. This step is critical to match the requirements with implementation opportunities and constraints to avoid exceeding time and budget, and the underperformance of the implemented technologies. (iii) guiding the digital transformation steps by roadmaps [7]. (iv) evaluating the implementation of the enabling technologies in various aspects (e.g. performance, use) by evaluation methodologies [2].

3 Industry-driven projects on digitalization in manufacturing

This section presents the research projects conducted and coordinated by the SINTEF research center within the area of digitalization in manufacturing. The projects were defined by combining the research interests with industrial partner requirements.

3.1 Circulær

CIRCULÆR promises to enable the Norwegian industry to tackle economic and environmental challenges by combining lean thinking and digitalization with circular economy (CE) principles. The European Green Deal defines the EU's environmental strategy and CE plan to halve waste by 2030. Following this notion, Norway's environmental policy brings to focus that its industries must reduce greenhouse gas emissions, minimize harmful discharges to water and increase energy efficiency. As such, the Norwegian industry must embark on the twin transition to zero- / low-emission solutions, while simultaneously advancing beyond the dominant (analog) linear economy, to remain competitive. For Norwegian companies, this transition requires new skills and capabilities throughout the organization. The underpinning idea and motivation for this project is to encourage and help organizations to discover and learn new ways of realizing opportunities for digitalization and circularity throughout their entire product portfolio.

3.2 Digitally-enhanced Operator

The Digitally enhanced Operator (DEO) project was a Norwegian user-driven innovation project aimed to strengthen the autonomy, situation awareness, and teamwork of the production shop floor operators. An autonomous approach supported by enabling technologies was taken to enable the operators to make effective decisions. Strengthening the situation awareness of the operators aimed at increasing their responsibility in production, by providing continuously updated production status, implications of status, and precise projections of what will happen in the future. At the same time, operators depend on effective coordination in their teams to take a larger area of responsibility. The project involved two use cases to investigate, test, evaluate, and implement the digitalization methods and technologies in pilot cases. The first use case involved a producer of jet engine components that focused on testing Augmented Reality glasses for operator learning, placing dashboards on the shop floor to increase the situation awareness of the operators, and integrating sensors into the production system to obtain an overview of machine status in real-time. The second use case involved a producer of machine dampening tools and focused on developing a decision support tool for situation awareness and production control in the assembly department. The project has also characterized the need for developing a maturity assessment tool to analyze and evaluate the level of digital support given to the production operators in their daily activities and tasks and point out the needs and priorities for digitalization efforts on the production shop floor toward the Operator 4.0.

3.3 HUman MANufacturing (HUMAN)

The HUman MANufacturing (HUMAN) project was a European H2020 project coordinated by SINTEF and aimed to develop a platform that supports the human operator in performing their tasks with the desired quality, whilst ensuring their well-being. Co-creation principles with iterative study and feedback loops were used to engage with the manufacturing companies and operators, elicit the requirements, and develop, test, evaluate, and deploy the solutions.

AR was the primary enabling technology tested and implemented in the use cases with the main goal to increase productivity while ensuring the well-being of the operators. Three distinct end-users contributed to this co-creation process. The first use case involved an airplane manufacturer, targeting the operator that assembles multiple clamps in the assembly department. Due to its repetitive nature, this process may lead to mistakes that require additional time for fixing thereby reducing the production rate in the assembly department. The deployed AR solution provided step-by-step instructions to the operator on what and how to assemble, complemented by the verification of correct assembly thereby reducing the error probability. The second use case involved a designer and producer of industrial robots, targeting the assembly of a robot forearm, where due to multiple options and configuration may lead to assembly mistakes. The AR solution provided stepwise instructions where a quality checkpoint verified the correct application of the sealant before allowing the operator to proceed with the assembly. The third use case involved a furniture manufacturer where the work is seasonal and requires the recruitment of additional operators who may lack the necessary knowledge. Their training may result in a reduction of productivity as more experienced operators are required to support the new trainees. The AR solution supported the training process and reduced the need of involving experienced operators and the time to competence. An evaluation method was developed to evaluate the use cases, consisting of the following life cycle stages: data collection, technical testing, UX testing formative evaluation study, and a final study. The details of the evaluation method are provided in [2].

3.4 Lean Digital

The lean-digitalization paradox: Toward strategic digitalization (Lean Digital) aims to develop theories and managerial guidelines for digitalization of Norwegian industry based on lean principles with respect to planning, decisions systems, supplier collaboration, and work organization. The main concepts in this research project are lean management and digital manufacturing technologies. We propose that novel theoretical insights can be developed by framing the relationship between the two main concepts as a paradox. These insights will form the basis for improved managerial guidelines, leading to greater levels of workplace innovation.

3.5 Lean 4.0

The Lean European Action-learning Network utilizing Industry 4.0 (LEAN 4.0) project is a European Erasmus+ Knowledge Alliance project that seeks to integrate Industry 4.0 smart technologies with the proven Lean Manufacturing paradigm. The four partner countries (Belgium, Germany, Netherlands, and Norway) face many of the same problems with skill development and are preparing to address this significant challenge together. A readiness assessment for Industry 4.0 technologies in Northern Europe’s high-value manufacturing industry has been created and deployed in the discrete manufacturing operations of four industry partners. A blended network action learning (BNAL) methodology has also been developed and is being used to guide problem-solving initiatives in the industry partners to develop digital lean solutions. LEAN 4.0 aims to develop novel education methods for the operations managers of the future.

3.6 SmartChain

The SmartChain was a Norwegian user-driven innovation project aimed at developing a lean value chain management system, by continuous real-time data exchange, monitoring, and control. The use case involved a producer of complex underwater surveillance systems, focusing on digitalizing the production value chain by designing, testing, and implementing a manufacturing execution system (MES). The project has initially focused on developing an overall digitalization strategy that considers lean implementation, establishes process stability and standardization, before automation and digitalization efforts. Once the suitable environment was established, a manufacturing execution system was designed, tested, and prototyped, involving the potential users of the system and benefitting largely from automation standards.

Table 1. Summary of the research projects on digitalization in manufacturing

Project	Application areas	Reference frameworks	Enabling technologies
Circulær	Lean manufacturing, Sustainable production value chains, New business models	Enterprise-wide value stream mapping, Life cycle analysis	Dashboard, Digital twin
Digitally Enhanced Operator	Production scheduling, monitoring and control, Operator training	Digital maturity assessment tool	Sensors, Dashboard, AR
HUMAN	Knowledge management Operator learning and training	Co-design principles Evaluation method	AR, Exoskeleton
Lean Digital	Digital Lean Manufacturing Sustainable production value chains	N/A	Sensors, Dashboards, Big data
Lean 4.0	Digital Lean Manufacturing	LEAN 4.0 Self-assessment	Smart glasses, Dashboards
Smart-Chain	Production value chain monitoring and control	Digitalization strategy, Automation standards (ISA95)	Manufacturing Execution System

4 Critical Areas for Digitalization in Manufacturing Industry

Based on the lessons learned from the previous and current research projects recently conducted at the SINTEF research center, the following trends, drivers, challenges, research areas are identified for digitalization in the Norwegian manufacturing industry.

4.1 Trends and drivers for digitalization in Norwegian manufacturing

Figure 1 illustrates the trends of digitalization in the Norwegian manufacturing industry and is explained below.

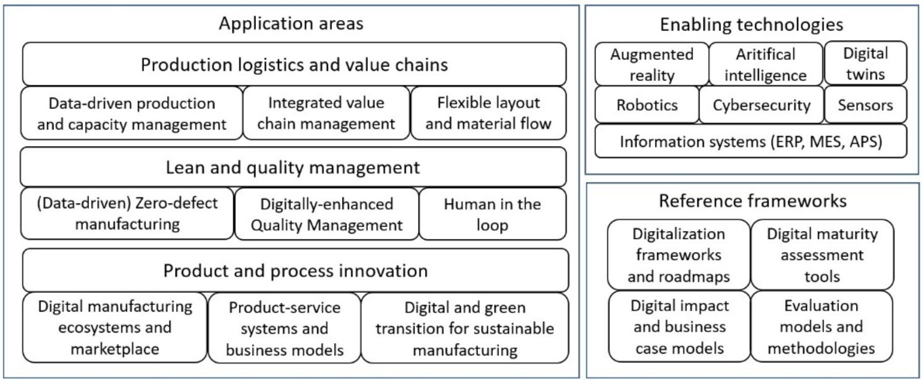

Fig. 1 Digitalization trends in the Norwegian manufacturing industry

Application areas for DiM. The main application areas in the Norwegian companies can be classified into the following three main areas:

1) Lean and quality management: This area incorporates the topics such as data-driven zero-defect manufacturing, digitally enhanced quality management, and human-in-the-loop that incorporates human-machine interface, knowledge sharing, technology-supported learning, and augmentation and autonomy of the workers are of great interest in the Norwegian context. These trends are largely driven by the following characteristics of the Norwegian manufacturing industry: (i) flat organizational structure that aims to increase the autonomy of the employees to take more responsibilities on the production system. (ii) competitiveness goals as a high-cost country in the production and delivery of the customized, technologically advanced, and complex products and services, which require a highly competent workforce (iii) while producing customized and advanced products, minimizing the operating costs.

2) Product and process innovation: This area incorporates the topics such as digital manufacturing ecosystems and marketplaces, digital and green transition for sustainable manufacturing, and product-service systems and business models. These trends are largely driven by the following characteristics of the Norwegian manufacturing industry: (i) growing sustainability concerns and regulations in Norway (ii) clustering strategy and initiatives of the Norwegian authorities and companies that has resulted in dozens of clusters all over the country to facilitate cooperation, collaboration, and co-innovation. (iii) creating new values from digital transformation and increase the competitiveness of the manufacturing industry, which largely depends on providing advanced and customized solutions.

3) Production logistics and value chains: This area incorporates the topics such as data-driven production and capacity management, integrated value chain execution and management, and flexible layout and material flow. The main drivers of these trends

are again minimizing the operating costs and providing the operating flexibility to deliver customized products and services.

Reference frameworks for DiM. Small and medium enterprises (SME) play a critical role in the Norwegian manufacturing industry. However, most SMEs have limited resources and digital transformation can quickly become too costly. SMEs require digitalization frameworks and roadmaps to guide the process, maturity assessment tools for assessing the digital maturity and readiness of the manufacturing environment, evaluation models and methods to evaluate the implementation of the digital tools in various aspects (e.g. performance, economic, user experience), as well as models to create business cases that can measure the digital value creation.

Enabling technologies for DiM. Common with most digitalization frameworks, the Norwegian manufacturing industry is also looking at the opportunities provided by augmented reality, autonomous robots, Big Data analytics, and artificial intelligence, as outlined in the research projects. Besides, manufacturing execution systems are gaining strong interest as a common platform for storing and sharing data, as well as providing the integration between the enterprise levels both horizontally and vertically.

4.2 Challenges

A prominent challenge for the successful digitalization of Norwegian manufacturing environments is the lack of consideration of human aspects. Acceptance of the enabling technology may vary between the employees, depending on whether they see the value created by the enabling technology in the work practices, on their interests in utilizing new technologies, and/or convincing the employees on the role of the technology to support their work rather than replacing their tasks. Data capture and exchange also imply important challenges. Most manufacturing companies still consist of old machines and equipment, making it difficult to implement real-time data acquisition solutions. While continuous data exchange is fundamental to achieve digitally integrated value chains and creating digital marketplaces, companies are reluctant to share information given the confidentiality concerns. Implementation of new technologies (e.g. real-time data capture by sensors, AR support) also implies potential changes in the allocation of the functions between the enterprise management levels, as the abilities to make decisions at the lower levels are strengthened. For example, enhancing the decision-making abilities of the operators requires considering the allocation of production scheduling and routing functions to the shop floor systems. As such, careful consideration of the functional processes is needed along with the digitalization project.

4.3 Research areas

Firstly, there is a need for studying efficient digitalization strategies for establishing the underlying needs of digitalization and creating a business case with clear links to value creation. Further, methodologies to guide the digitalization are needed, encompassing the requirement elicitation of the companies, ensuring the match between the requirements and technologies, application of the enabling technologies, and evaluating the implementation. Demonstration pilots in our projects have also shown that there is still a need for further development of the core enabling technologies, to make them more application-friendly in the industry. For example, users were reluctant to carry AR glasses in their work practice due to ergonomic challenges. Lastly, more field-based studies on post-implementation experiences are needed to verify the potential benefits, to better understand the critical factors for a successful digitalization process, and modify the guiding frameworks and methodologies.

Conclusion

The discussed trends, challenges, and research areas for digitalization in manufacturing are connected to our experiences with research projects in Norway. They are not comprehensive but provide practical insights on the digitalization of real industrial work environments towards establishing a good practice of research on digitalization in manufacturing. This study was partially funded by the SINTEF research center through strategic funding.

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