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The digitalization of manufacturing: Investigating the impact of production environment and company size

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Abstract

Purpose – While manufacturing digitalization is currently considered an important enabler of competitive advantage, its applicability across the industrial spectrum is unclear. This paper aims 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.

Design/methodology/approach – This study is based on data gathered from a survey questionnaire sent to 212 Norwegian manufacturing companies. To test the formulated hypotheses, the two-way analysis of variance (ANOVA) method was used.

Findings – This study confirmed that large enterprises (LEs) have a significantly higher level of shop floor digitalization and organizational IT competence than small and medium-sized enterprises (SMEs). Regarding the difference between production environments, no statistically significant difference in the implementation level of the investigated digitalization aspects could be found.

Originality/value – To the best of the authors' knowledge, this is one of the first studies to investigate differences in the adoption of digital technologies between different groups of production environments. This study also provides updated findings related to the relationship between digitalization and company size. The findings presented in this paper provide important insights into directing future research efforts to assist environments that are currently lagging behind in their digital transformation.

Keywords Digitalization, Industry 4.0, Digital technologies, Production environments, Survey

Paper type Research Paper

1. Introduction

Steadily increasing competition puts companies under tremendous pressure to innovate and improve their operations strategies and processes in order to remain competitive and meet the changing requirements of the market (Birkie, 2015). Manufacturing companies throughout the last century have adopted numerous methodologies in order to improve the management of their operations. Notable examples include Fredrick Taylor's scientific management, lean manufacturing, material requirements planning (MRP), and enterprise resource planning (ERP). More recently, advanced IT solutions, typically under the umbrella of Industry 4.0, have gained traction and popularity among consultants and academicians. They are currently considered as important enablers of competitive advantage, which can be understood from how numerous governments have focused on the digitalization of industry (European Commission, 2017; Liao *et al.*, 2017). However, the implementation in manufacturing companies seems to be slower. Most manufacturing companies are still in the early stages of implementing such technologies and are thus at a more basic level of IT usage than is typically associated with Industry 4.0 (Bley *et al.*, 2016; Van den Bossche *et al.*, 2016; Moeuf *et al.*, 2018). This also seems to be the case for Norwegian manufacturing companies (Eleftheriadis and Myklebust, 2017; Torvatn *et al.*, 2019).

Nevertheless, moving toward the Industry 4.0 vision must be seen as a stepwise process, and different prerequisites should be in place. Klötzer and Pflaum (2017) argued that lean manufacturing remains the basic prerequisite for the digitalization of manufacturing. Furthermore, Pfohl *et al.* (2017)

have pointed out the digitalization of processes and products as a key enabler of Industry 4.0. Bosch (2018) summarized the process of moving toward Industry 4.0 in three steps: First, a streamlined process as a result of a lean transformation; second, an enabled factory with the required IT architecture; and third, a connected factory taking advantage of the latest advancements, such as cloud computing, cyber-physical systems (CPS), and the Internet of Things (IoT).

Earlier research has emphasized the need for a "fit" between technology and the environment in which it is implemented (Congden, 2005). Although Industry 4.0 pilot projects can be observed across the industrial spectrum, the actual universality of the technologies associated with Industry 4.0 remains unclear (Sommer, 2015; Strandhagen *et al.*, 2017). This concerns both the applicability across different production environments as well as company sizes. Through an investigation of four case companies, Strandhagen *et al.* (2017) proposed that manufacturers with higher levels of repetitiveness also see the largest potential benefits from Industry 4.0. Other researchers have questioned whether Industry 4.0 is solely for large enterprises (Sommer, 2015; Rüttimann and Stöckli, 2016).

The successful implementation of digital technologies in manufacturing is often touted as being the next enabler of performance improvement in manufacturing, and a necessity for manufacturers to stay competitive. To ensure an appropriate digitalization of the manufacturing sector, research should also focus on investigating in which environments such technologies fit. The objective of this study is to uncover differences in the implementation level of various aspects of digitalization across differing production environments and company sizes. The digitalization aspects investigated in this study are *shop floor digitalization, technologies for vertical and horizontal integration,* and *organizational IT competence.* Each of these aspects is considered an important enabler for moving toward a smart factory, as described in the Industry 4.0 vision (Kagermann *et al.*, 2013). By developing hypotheses based on propositions from earlier research, this study used data collected from a cross-sectional survey to investigate the context-dependency of manufacturing digitalization. The paper is structured as follows: Section 2 introduces the theoretical background and the proposed research hypotheses. The research method for this study is described in Section 3. The data analysis and research findings are described in Section 4, while the implications of these findings are discussed in Section 5. Finally, Section 6 concludes the paper.

2. Literature background

2.1 Digitalization of manufacturing

Industry 4.0 can be described as an umbrella term, referring to a range of current concepts and touching several disciplines within industry (Lasi *et al.*, 2014). The key drivers for this fourth industrial revolution can be divided into two aspects. The first is the combination of rapidly advancing technological developments of today, including IoT, Internet of Services (IoS), CPS, augmented reality, artificial intelligence (AI), and big data analytics. The introduction of such technologies may result in a paradigm shift in industrial production (Lasi *et al.*, 2014), and this can be described as a *technology push*. This technology push can enable significant advances in the manufacturing industry. The second aspect is the demand from manufacturing companies, especially in countries with high cost levels, to make themselves independent of high labor costs by exploiting new technology. Businesses will seek new ways of offering their products and services, and new business models will often emerge as a result (Kagermann *et al.*, 2013; Rachinger *et al.*, 2019).

Digitalization and the technologies within Industry 4.0 are expected to cause disruptive changes in industrial manufacturing. Industry 4.0 includes several technological advances that can have a significant positive impact on manufacturing logistics processes and activities, which are concerned with managing the internal logistics flows required for the manufacture of products. These include innovations in already existing technologies, as well as the development of entirely new technologies.

The official Industrie 4.0 Working Group highlights three overarching features of Industry 4.0: horizontal integration through value networks, end-to-end digital integration of engineering across the entire value chain, and vertical integration and networked manufacturing systems (Kagermann *et al.*, 2013). Additionally, they outline smart products and smart factories as key enablers of the Industry 4.0

vision. Their perspective of Industry 4.0 is thus a smart manufacturing system that is integrated with different business functions and supply chain partners. Following this definition, we focus on three important aspects of the digitalization of manufacturing operations: *1) shop floor digitalization, 2) technologies for vertical and horizontal integration*, and *3) organizational IT competence*. Figure 1 illustrates the three aspects in the context of a manufacturing value chain. While the first two aspects focus on technology, the third is about organizational enablers for digitalization. As mentioned previously, each is considered an important enabler for moving toward a smart factory (Kagermann *et al.*, 2013). The three aspects are briefly introduced below:

- ***Shop floor digitalization.*** Digitalization of the shop floor creates the necessary link for integrating the physical components and resources with the digital world of data and information processing. CPS, and more specifically, cyber-physical production systems, is the key element of such a digitalization, as it realizes this integration through the use of sensors, actuators, control processing units, and communication devices (Hofmann and Rüsch, 2017). In a digitalized shop floor, machine and sensor data are collected at the level of the physical objects along the entire value stream, and via a connectivity layer, the gathered data are provided for analytics. Through the integration of these technologies, real-time production data can be collected and shared to facilitate rapid and accurate decision-making through intelligent decision support systems (Ghobakhloo, 2018; Zheng *et al.*, 2018). The access to real-time information on the status and specific changes of components, people, machines, or processes on the shop floor allows for continuous and real-time planning and control of manufacturing operations.
- ***Technologies for vertical and horizontal integration.*** Vertical integration concerns the integration of various IT systems at the different hierarchical levels inside a factory (e.g., production actuators and sensors, enterprise systems, and product development) and is a central feature of the Industry 4.0 vision (Kagermann *et al.*, 2013; Wang *et al.*, 2016). Horizontal integration refers to "the integration of the various IT systems used in the different stages of the manufacturing and business planning processes" (Kagermann *et al.*, 2013, p. 20). This can be both internally within a company (e.g., from sales forecasting, through production, to warehouse planning and logistics), or among different partners in the value chain (value networks).
- ***Organizational IT competence.*** Early research on the use of IT in organizations observed what we now know as the "productivity paradox" (Brynjolfsson, 1993), which highlighted the apparent lack of a link between IT investments and productivity gains. These findings motivated studies to determine which factors enabled a successful adoption of IT systems. A number of these enablers are related to organizational capabilities, in particular, IT competence (Byrd and Davidson, 2003; Davis, 2013). Organizational IT competence is conceptualized as an organization's understanding and effective utilization of IT (Tippins and Sohi, 2003; Yoon, 2011). Factors that have been mentioned as important enablers of efficient use of IT includes the technical quality of an organization's IT department (Byrd and Davidson, 2003), top management support (Thong *et al.*, 1996; Byrd and Davidson, 2003), and systematic approaches to handle and use available data (Schmidt *et al.*, 2015).

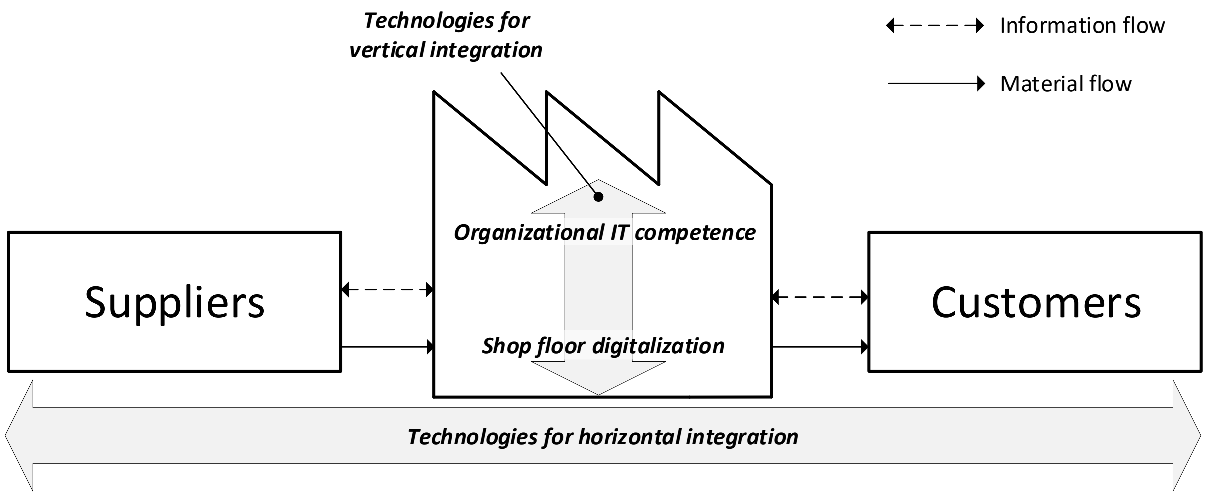

Figure 1. An overview of the digitalization aspects investigated in this study

2.2 The relationship between digitalization and production environment

In a broad sense, a production environment can be defined as "the sum of internal and external variables that influence the production planning and control process" (Buer *et al.*, 2018b, p. 79). It is the environment in which manufacturing strategy is developed and implemented (Blackstone, 2013).

The degree of production repetitiveness is a characteristic often used to describe production environments (MacCarthy and Fernandes, 2000). Repetitive production typically refers to the high-volume production of a low variety of products, often with a make-to-stock (MTS) or assemble-to-order (ATO) approach. Less repetitive production environments typically produce in lower volumes, with a higher product variety, and have more complex product routings and material flows. The make-to-order (MTO) or engineer-to-order (ETO) approaches are more typical for non-repetitive production environments (Olhager, 2003). Thus, the placement of the customer order decoupling point (CODP), which indicates whether a company is MTS, ATO, MTO, or ETO, can give a rough description of a company's production environment. However, to give a more holistic description, several other variables must be considered.

In addition to the placement of the CODP, a range of other variables can be used to characterize a production environment. With these numerous environmental variables in mind, and knowing that companies can differ significantly even if they share the placement of their CODP, Jonsson and Mattsson (2003) defined four distinctive types of production environments. These are presented in Table I. This typology, to a large degree, highlights the differences between production environments rather than a grouping solely based on the CODP, while simultaneously ensuring strong intra-group similarities.

Table I. Characteristics of the four types of production environment (Adapted from Jonsson and Mattsson, 2003)

	Production environment			
	Complex customer order production	**Configure-to-order production**	**Batch production of standardized products**	**Repetitive mass production**
Product complexity	High	Medium	Medium	Low
CODP	ETO/MTO	ATO/MTO	MTS	MTS
Product variety	High	High/medium	Medium/low	Low
Volume	Low	Medium	High	High
Standardization	Low	Medium	High	High
Batch sizes	Small	Small	Medium/large	Large/continuous production
Lead times	Long	Medium	Medium	Short

The production environment is known to have implications for a range of different aspects of production management. Several studies have investigated the importance of the production environment regarding material planning methods or production control systems and found that the applicability of the different methods and systems was affected by the production environment (e.g., White and Prybutok, 2001; Jonsson and Mattsson, 2003; Fernandes and Godinho Filho, 2011). Congden (2005) investigated the strategic fit between different competitive strategies and manufacturing technologies. The results confirmed that repetitive manufacturing companies use both "fixed" and flexible computerized automation solutions more than non-repetitive manufacturing companies. The production environment has also been found to be of relevance regarding digitalization and the applicability of digital technologies, as there were indications that the degree of repetitiveness in the production environment was a factor affecting applicability (Strandhagen *et al.*, 2017). As shown, earlier studies have indicated that different production environments require different approaches to production planning and control, technology application, and improvement programs (e.g., lean manufacturing), and there is no one-size-fits-all approach to these issues.

Through an extensive analysis of existing research, Zennaro *et al.* (2019) found that the aspect of digitalization in non-repetitive production, especially in one-of-a-kind manufacturing, has been an insufficiently researched area. Strandhagen *et al.* (2017) presented several aspects of repetitive production environments, which suggested that digital technologies are more applicable in these environments. The lower complexity and higher standardization of material flows, facility layout, and product structures facilitate the sensorization of the production processes and, in turn, the collection of production data. These environments also generally have a higher degree of automation and are thus closer to the Industry 4.0 vision (Kagermann *et al.*, 2013) than less repetitive production environments characterized by a larger degree of manual processes (Sjøbakk *et al.*, 2014). The existing literature indicates that a company's production environment can be an explanatory factor concerning the applicability of digital technologies on the shop floor. Therefore, we propose the following hypothesis:

> *H1.* There is a significant difference in the level of *shop floor digitalization* among the four groups of production environments.

Aslan *et al.* (2012) discuss the fit between ERP systems and companies using an MTO production strategy. They found that most of the widely available ERP features fail to match the requirements of MTO manufacturers. Olsen and Sætre (2007) also raised the question of whether an ERP system is the best solution for companies operating in niche markets. They argued that these companies' distinctiveness in offering customized products to a small market niche necessarily calls for more in-house development of software to make use of certain functions offered in off-the-shelf ERP systems. The higher proportion of manual labor typically seen in manufacturing companies producing complex customer orders might also hinder efforts to integrate production equipment with each other, as well as vertically with other systems (Strandhagen *et al.*, 2019). Furthermore, the internal information flow (e.g., between engineering and production) in these kinds of manufacturers is typically not integrated (Mello *et al.*, 2017).

It has previously been suggested that it can be more challenging for ETO companies to achieve close supplier relationships because their suppliers are typically used infrequently and in low volumes (Stavrulaki and Davis, 2010). As different companies often use different information systems, the more unstable supplier and customer relationships of ETO companies could make it less appealing to make investments to align their enterprise system with other actors in the supply chain (Mello and Strandhagen, 2011). In general, lack of shared IT systems and lack of collaboration are mentioned as typical challenges in ETO supply chains (Gosling *et al.*, 2015). Earlier research studies thus indicate that non-repetitive manufacturers face challenges that could affect their potential to use technologies for vertical and horizontal integration. Based on this, we propose the following hypothesis:

> *H2.* There is a significant difference in the level of *technologies for vertical and horizontal integration* among the four groups of production environments.

Being able to make the most out of emerging technologies requires advanced technical knowledge, typically provided by an organization's IT department. Earlier studies have suggested that repetitive manufacturers tend to use computerized automation solutions and enterprise systems to a larger degree than non-repetitive manufacturing companies (Sjøbakk *et al.*, 2014; Gosling *et al.*, 2015). It may be assumed that repetitive manufacturers typically have worked longer with such solutions, and thus have had more time to build up in-house competence in this area. Relating to Porter's competitive strategies (Porter, 1980) and Fisher's supply chain strategies (Fisher, 1997), non-repetitive manufacturers tend to focus on differentiation rather than cost leadership. Therefore, these companies may focus more on product development rather than process development. As such, building competence regarding the implementation and operation of advanced digital systems might be given less priority. Based on this, we propose the following hypothesis:

> *H3.* There is a significant difference in the level of *organizational IT competence* among the four groups of production environments.

2.3 The relationship between digitalization and company size

Small and medium-sized enterprises (SMEs) often face difficulties in their business environment, such as lower productivity, slow growth, limited access to financial resources, and lower rates of innovation and technology adoption (European Commission, 2008). Moreover, the adoption of IT is especially challenging for SMEs (Nguyen, 2009).

However, the global implementation of Industry 4.0 also requires implementation in SMEs, as they constitute a large portion of today's industry (Sommer, 2015). Furthermore, the potential of digitalization is not limited to large enterprises (LEs), as it concerns all stages and areas of industrial supply chains and can offer significant opportunities for SMEs (Li *et al.*, 2016). SMEs have motives for exploring Industry 4.0, as its general benefits of profitable growth through new products, new services and innovative business models, and increased efficiency and reduced costs through digitalization are important advantages independent of company size (Bley *et al.*, 2016). Close collaboration with vendors and tailored solutions have been proposed as keys for smaller companies with regards to succeeding with digitalization (Mittal *et al.*, 2018).

Although there are arguments for why SMEs could benefit from implementing emerging digital technologies, there are also critical barriers to implementation in SMEs. Recent research has suggested that the implementation of Industry 4.0 is affected by company size, favoring LEs over SMEs (Müller *et al.*, 2018). Smaller companies feel less prepared for Industry 4.0, as the company size affects the companies' financial and technological capabilities (Sommer, 2015). The high investments needed for Industry 4.0 implementation will increase the related operational break-even point (Rüttimann and Stöckli, 2016). Other challenges faced by SMEs in moving toward Industry 4.0 include low production volumes, less standardization, less access to skilled employees, and concerns regarding data security (Müller, 2019). SMEs tend to perceive the concepts within digitalization as too complex and expensive, and not relevant (Bley *et al.*, 2016). The features that distinguish smaller companies from large companies may call for different approaches to digitalization, and the relationship between company size and digitalization needs further investigation.

Kennedy and Hyland (2003) presented evidence that SMEs to a lesser degree use advanced manufacturing technologies (AMTs) than LEs. They also found that SMEs received a lower payoff from implementing such technologies. The fact that SMEs have less advanced equipment to start with could be a barrier for shop floor digitalization (Mittal *et al.*, 2018). Furthermore, SMEs lack the economies of scale and bargaining power with suppliers of equipment and software systems, in contrast to LEs (Malekifar *et al.*, 2014). It is clear that larger companies can dedicate more resources to developing their IT infrastructure, and their larger turnover enables a shorter payback period for these investments. Therefore, SMEs might feel there is a larger risk of implementing emerging digital technologies than it is for LEs. Researchers have thus proposed that LEs to a larger degree have been able to implement digital solutions in their manufacturing operations. Based on this, we propose the following hypotheses:

H4. Company size is positively associated with the level of *shop floor digitalization.*

Buonanno *et al.* (2005) found that company size is a significant predictor of ERP adoption and found that this was mainly due to structural and organizational factors. SMEs did not, for example, regard their business as complex enough to justify the implementation of an ERP system, or they lacked the organizational skills to manage the changes incurred by an ERP system. Larger companies usually have more complex supply chain networks resulting in a need for more effective management of their supply chain, while smaller companies typically deal with fewer customers and suppliers and might thus not see the need to invest in such software (Li *et al.*, 2006). In general, it has been suggested that, when compared to LEs, SMEs lag behind in their degree of IT integration (Mittal *et al.*, 2018). Therefore, we propose the following hypothesis:

H5. Company size is positively associated with the level of *technologies for vertical and horizontal integration*.

Regarding organizational IT competence, there have been some previous studies regarding differences between SMEs and LEs. Arendt (2008) cites the lack of knowledge, education, and skill of managers and employees as one of the main barriers to IT adoption in SMEs. Employees in SMEs are more likely to be generalists and do not necessarily have the possibility to develop high levels of expertise within one area (Bublitz and Noseleit, 2014). This includes expertise regarding IT and automation, and it has been proposed that SMEs lack the technical resources necessary to implement Industry 4.0 related technologies (European Commission, 2015; European Commission, 2017; Mittal *et al.*, 2018). Moreover, SMEs do not typically have dedicated research and development personnel, and it has been found that SMEs lag behind LEs regarding innovation culture and strategy (Terziovski, 2010). While LEs often have strategy departments or Industry 4.0 groups working on digitalization (Mittal *et al.*, 2018), SMEs often lack business and IT strategies to guide the adoption of IT (Nguyen, 2009). Additionally, SMEs are typically less involved in research projects and collaborations with universities and research organizations than LEs (Mittal *et al.*, 2018). Based on these findings, we propose the following hypothesis:

H6. Company size is positively associated with the level of *organizational IT competence*.

The research framework for this study is presented in Figure 2.

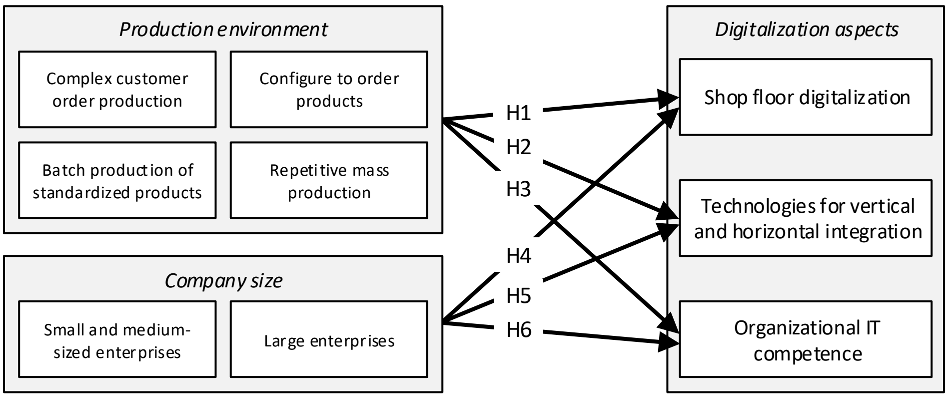

Figure 2. Research framework

3. Research method

3.1 Sampling procedure

As part of a research study mapping Norwegian manufacturers, a questionnaire was emailed to 212 Norwegian manufacturing companies. The sample was gathered from a company database consisting of companies participating in a knowledge-sharing platform for manufacturing logistics. The companies in the sample were from a variety of sectors, ranging from small to large enterprises and across different geographical locations in Norway. The responses were collected from April to August of 2018. In total, 76 usable responses were collected, which corresponded to a response rate of 35.8%. The surveys were primarily sent out to management representatives of the companies, who were assumed to have the required knowledge to answer the questions in all of the categories. Table II shows the sample composition.

Table II. Demographics of the sample (*n* = 76)

		Number of respondents	**Sample (%)**
Industrial sector	Machinery	14	18.4 %
	Chemical	12	15.8 %
	Fabricated metal products	9	11.8 %
	Food and beverage	8	10.5 %
	Electronics	7	9.2 %
	Furniture	5	6.6 %
	Fabricated wood products	5	6.6 %
	Shipyard	5	6.6 %
	Automotive	4	5.3 %
	Other	7	9.2 %
Respondent's profile	Production manager	22	28.9 %
	CEO	15	19.7 %
	CTO	8	10.5 %
	Supply chain manager	8	10.5 %
	Improvement manager	8	10.5 %
	Project manager	4	5.3 %
	Other	11	14.5 %
Production environment	Complex customer order production	25	32.9 %
	Configure to order products	16	21.1 %
	Batch production of standardized products	21	27.6 %
	Repetitive mass production	14	18.4 %
Company size	Small and medium-sized enterprises	36	47.4 %
	Large enterprises	40	52.6 %

To assess the possibility of non-response bias, we compared the responses to the two control variables production environment and company size, as well as five random questionnaire items, between the early (responded during the first two months, *n* = 46) and late respondents (responded during the last two months, *n* = 30). The chi-square tests for all seven indicated no statistically significant difference between the early and late respondents, with a significance of 0.05. This indicates an absence of non-response bias (Khanchanapong *et al.*, 2014; Chavez *et al.*, 2015).

3.2 Measures

The distributed questionnaire was divided into two parts. The first part mapped the company-specific characteristics, such as respondent background, sector, and company size (number of employees and annual turnover). Additionally, the companies were asked to assess their type of production environment based on the four types described in Section 2.2. Each of the four types of production environment was described in detail in the survey, and the respondents were asked to pick the type that was the closest match. These descriptions can be found in the Appendix. Regarding company size, the responding companies were classified as either SMEs or LEs based on the definition from the European Commission (2003). According to this definition, an SME is a company that has both a staff headcount below 250 employees and a yearly turnover of less than or equal to €50 million. If the company exceeds either of these two criteria, they are defined as an LE.

Regarding Industry 4.0 and digitalization, established measurement scales are scarce. There is still confusion surrounding the domain, both in content and semantics (Buer *et al.*, 2018a; Moeuf *et al.*, 2018). For this study, mainly focusing on the digitalization of manufacturing, the "Industry 4.0 Self-

Assessment model" (Geissbauer *et al.*, 2015) was used as a foundation. This model provides detailed explanations and illustrative examples for each measurement and is more focused on capabilities rather than specific technologies. Measurements from the categories related to value chains and processes, IT architecture, and organization and culture were adapted into a measurement tool consisting of 13 measures. The rating system consisted of 5-point Likert scales, where 1 represented no implementation and 5 a complete implementation. Since this is still an emerging area, the respondents received extra information and examples for each of these questions to help them rate their own company. These questionnaire items can be found in Table III.

3.3 Validation

The validation of the survey instrument was conducted in two phases, the first before distributing it and the second after collecting the responses. Before it was sent out to the respondents, a validation of the individual questionnaire items and a pre-test of the questionnaire were done by two independent academicians with experience in both research projects and industry. This was to ensure the *content validity* of the questionnaire.

After collecting the responses, the survey instrument was validated by investigating its *construct validity* and *reliability*. Two aspects of construct validity should be considered: *convergent validity* and *discriminant validity* (Forza, 2002). To assess the *convergent validity,* we first assessed the *unidimensionality* of the measures. This was done through principal component analysis. Following the recommendations of Carmines and Zeller (1979), the items for each of the constructs were analyzed separately. In all of the analyses, the items loaded on a single factor, and the eigenvalue exceeded 1.0. For each construct, the total variance explained exceeded 50%, and all of the items' loading factors were above 0.5, thus supporting unidimensionality. To further assess the convergent validity, the average variance extracted (AVE) and composite reliability (CR) of the constructs were calculated. The recommended thresholds for good convergent validity for these two tests are AVE > 0.5 and CR > 0.7 (Hair *et al.*, 2010). The values for AVE and CR are presented in Table III and are above the recommended values. To assess *discriminant validity,* we followed the recommendations of Fornell and Larcker (1981). They stated that to ensure discriminant validity, the AVE for each construct should be greater than the square of the construct's bivariate correlations with the other constructs (Table IV). In all cases, these criteria were satisfied. Based on these tests, we assumed sufficient construct validity. To test the *reliability* of the constructs, the Cronbach's α coefficient was calculated. Table III shows the analysis of construct validity for the constructs where multiple items were combined into one construct. All the α values were above 0.7, which indicated reliable scales for further analysis (Forza, 2002).

Common method bias is typically a risk when there is only a single respondent in each company. To mitigate this risk, we used a two-step approach. First, the questionnaire was designed according to the recommendations of Podsakoff *et al.* (2003). This implied separating the dependent from the independent variables in the questionnaire and emphasizing in the survey invitation that the responses would be treated confidentially and would be kept anonymous. The second step was to analyze the collected data using Harman's single factor test. This was done by loading all independent and dependent variables into an exploratory factor analysis. This resulted in a first factor that explained 33.5% of the variance, well below the recommended threshold of 50% (Podsakoff *et al.*, 2003). Common method bias was therefore assumed not to be a concern in this study.

Table III. Scale validity and reliability

Scales	Items	Factor loading
Shop floor digitalization AVE = 0.554 CR = 0.831 Cronbach's α = 0.726	To what extent do you have a real-time view of your production and can dynamically react to changes in demand?	0.621
	How advanced is the digitalization of your production equipment (sensors, Internet of Things [IoT] connection, digital monitoring, control, optimization, and automation)?	0.777
	To what extent does your IT architecture (hardware) address the overall requirements of digitalization and Industry 4.0?	0.802
	To what extent do you use a manufacturing execution system (MES) or similar to control your manufacturing process?	0.764
Technologies for vertical and horizontal integration AVE = 0.535 CR = 0.821 Cronbach's α = 0.706	How would you rate the degree of digitalization of your vertical value chain (from product development to production)?	0.663
	To what degree do you have an end-to-end IT-enabled planning and control process from sales forecasting, over production to warehouse planning and logistics?	0.776
	How would you rate the degree of digitalization of your horizontal value chain (from customer order over supplier, production, and logistics to service)?	0.774
	How advanced is your IT integration with customers, suppliers, and fulfillment partners?	0.707
Organizational IT competence AVE = 0.566 CR = 0.866 Cronbach's α = 0.804	How would you rate your capability to create value from data?	0.652
	How would you rate your capabilities and resources related to Industry 4.0 (e.g., data analytics, IoT, CPS, human-machine interface, production security, digital product lifecycle management, etc.) in your organization?	0.845
	What level of involvement, support, and expertise do executive and senior management have in your organization with regards to Industry 4.0?	0.816
	To which extent is your IT organization able to fulfill business requirements in the requested time, quality, and cost?	0.693
	To which extent does your organization institutionalize collaboration on Industry 4.0 topics along with external partners such as academia, industry, suppliers, or customers?	0.738

4. Data analysis and results

4.1 Descriptive statistics

The means and standard deviations (*SD*) of the constructs, as well as their bivariate correlations, are presented in Table IV. There were highly significant correlations among all of the three constructs measured, suggesting that the implementation of these three aspects tend to be related. Further, the results were grouped based on the type of production environment and company size (Table V). These descriptive statistics provided an overview of the current digitalization trends in manufacturing companies and gave indications of group differences. *Batch production of standardized products* had the highest mean in all three categories, while *complex customer order production* had the lowest mean regarding shop floor digitalization and technologies for vertical and horizontal integration. This was mostly in line with the predictions of Strandhagen *et al.* (2017), who predicted that the applicability of Industry 4.0 increases with the degree of repetitiveness in the production environment. Our findings indicated this to a certain degree, but the highly repetitive production environments reported having a somewhat lower implementation degree than that of *batch production of standardized products*. When the results were grouped by company size, it was clear that LEs generally scored higher than SMEs. These initial findings seem to support the arguments of Sommer (2015) and Rüttimann and Stöckli (2016), who claimed that the largest enterprises most easily can exploit the possibilities of the advanced IT solutions branded under the Industry 4.0 umbrella. However, whether these differences were statistically significant was further investigated with a two-way analysis of variance (ANOVA).

Table IV. Means, *SD*, and correlations of the different constructs

			Correlations			
	Mean	***SD***	**1**	**2**	**3**	**4**
1. Production environment	2.32	1.12	-			
2. Company size	1.53	0.50	0.080	-		
3. Shop floor digitalization	2.80	0.73	0.184	0.270*	-	
4. Technologies for vertical and horizontal integration	2.91	0.69	0.092	0.074	0.634***	-
5. Organizational IT competence	2.81	0.79	-0.044	0.198	0.502***	0.546***
Notes: $*p < 0.05$; $***p < 0.001$						

Table V. Descriptive statistics grouped by production environment and company size

	Production environment								**Company size**			
	Complex customer order production (n = 25)		**Configure to order products (n = 16)**		**Batch production of standardized products (n = 21)**		**Repetitive mass production (n = 14)**		**SMEs (n = 36)**		**LEs (n = 40)**	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Shop floor digitalization	2.54	0.66	2.92	0.69	3.02	0.82	2.80	0.65	2.60	0.64	2.99	0.76
Technologies for vertical and horizontal integration	2.82	0.68	2.86	0.58	3.08	0.81	2.89	0.63	2.86	0.63	2.96	0.74
Organizational IT competence	2.85	0.85	2.77	0.87	2.87	0.81	2.70	0.57	2.65	0.79	2.96	0.76

4.2 Two-way ANOVA

To test the proposed hypotheses, the two-way ANOVA method was used. The benefit of using a two-way ANOVA over a traditional ANOVA is that it can simultaneously investigate and control for group differences in two independent or grouping variables. Thus, it was possible to uncover whether any unique interaction effects between production environment and company size resulted in an especially high or low mean value for any of the dependent variables. To do a two-way ANOVA, the required assumptions are normality, the absence of outliers, and equality of variances of the dependent variables (Hair *et al.*, 2010). These assumptions must be valid for all cells of the research design, that is, the eight unique combinations of production environment and company size. To assess the normality, the residuals in each group were visually inspected by using normal Q-Q plots. As an additional test, the kurtosis and skewness values were investigated. All were within the recommendations of Hair *et al.* (2010), and we could thus assume normality. No outliers were detected through the inspection of boxplots. To assess the equality of variances, we used Levene's test of equality of error variances. This did not show any significance in the dependent variables ($p > 0.05$), and we assumed equality of variances across the different groups. We could, therefore, proceed with interpreting the results from the two-way ANOVA.

The results from the two way-ANOVA are presented in Table VI. As shown, there were no significant interaction effects between production environment and company size, and we could proceed with investigating the main effects for hypothesis testing. These results supported *H4* and *H6*, while *H1*, *H2*, *H3*, and *H5* were rejected. Based on these findings, an updated research framework was constructed (Figure 3). The results from the two-way ANOVA are further visualized in Figure 4 to illustrate the implications of these findings. Figure 4 illustrates the context-dependency of the three digitalization aspects, that is, whether their implementation levels are related to the type of production environment and company size.

Table VI. Results from the two-way ANOVA

		ANOVA *F*-value	**Effect size[a]**
Production environment	Shop floor digitalization	1.400	0.051
	Technologies for vertical and horizontal integration	0.208	0.009
	Organizational IT competence	0.114	0.005
Company size	Shop floor digitalization	5.056*	0.062
	Technologies for vertical and horizontal integration	0.182	0.003
	Organizational IT competence	2.823[†]	0.039
Production environment × company size	Shop floor digitalization	1.127	0.041
	Technologies for vertical and horizontal integration	0.689	0.029
	Organizational IT competence	0.508	0.021

Notes: [†]$p < 0.1$; *$p < 0.05$. [a]Reports eta-squared (η^2). Effect sizes from eta-squared: small = 0.01-0.06, medium = 0.06-0.138, large > 0.138.

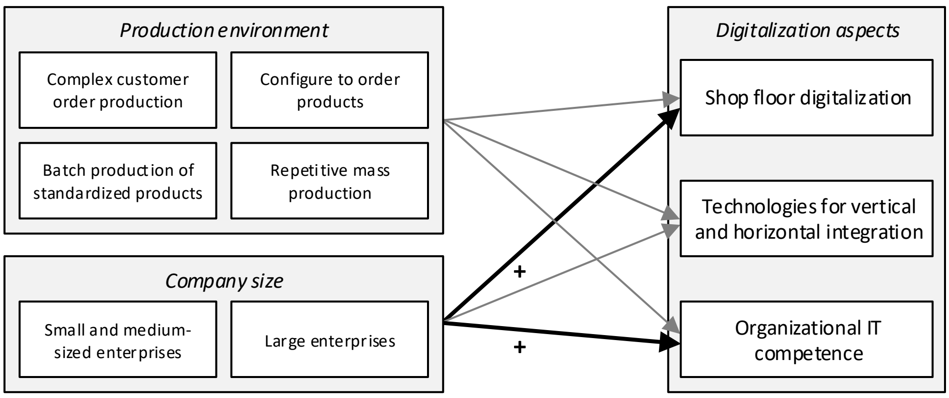

Figure 3. Adjusted research framework. Supported hypotheses are marked in black, while rejected hypotheses are marked in grey.

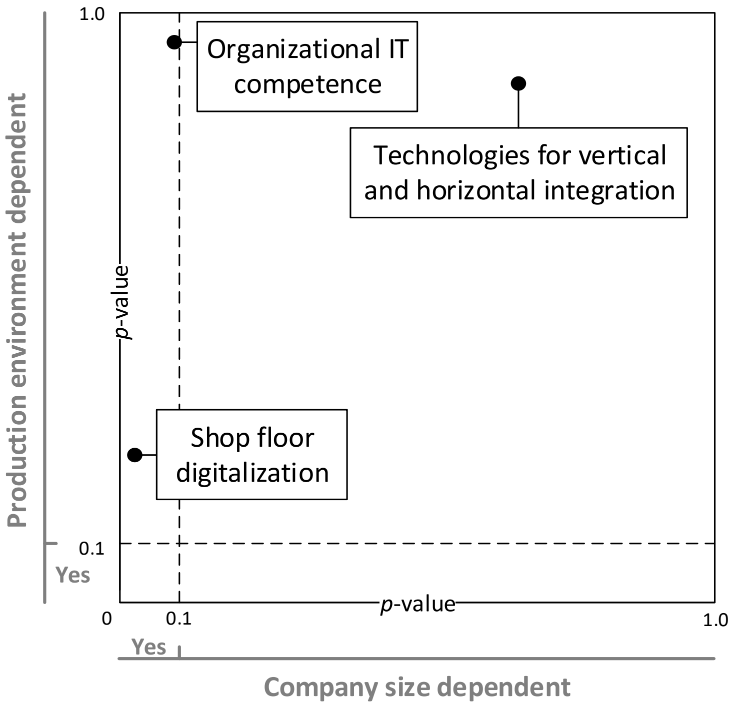

Figure 4. The context-dependency of digitalization

5. Discussion

This section will discuss the results and compare them with the initial hypotheses and existing theory. Thereafter, the implications of the study will be outlined.

5.1 The impact of production environment

The three hypotheses concerning significant implementation level differences among production environments were rejected, and the null hypotheses stood. Thus, digitalization appears to be less dependent on the production environment than other prominent domains in manufacturing, for example, lean manufacturing (White and Prybutok, 2001). Next, we will further examine the results from the testing of each of the three hypotheses related to production environments.

Based on the mean values in Table V, there were indications that companies producing complex, one-of-a-kind products lag behind in their shop floor digitalization. However, we could not prove any statistically significant difference regarding the level of shop floor digitalization among the production environments. Based on the findings of Strandhagen *et al.* (2017), we expected that the repetitiveness of the production processes would facilitate the digitalization of the production shop floor because of the lower complexity and higher degree of standardization. Rejecting *H1* is thus contradictory to the earlier propositions of Strandhagen *et al.* (2017), but it should be noted that the measurements were slightly different. While that particular study examined the applicability of different technologies, the current study measured the actual implementation level. By this, we mean that although some technologies may be considered applicable to a manufacturing environment, there may still be a time delay before they are actually implemented. Thus, the implementation level of a certain technology may deviate from its applicability. Although non-repetitive manufacturers typically have been characterized by lower levels of standardization and automation, recent studies have indicated that such environments are increasing both their levels of standardization (Vollmar and Gepp, 2015) and automation (Sjøbakk *et al.*, 2014). The steady increase in the industrialization of non-repetitive manufacturers may explain why they seem to keep pace with repetitive manufactures in terms of digitalization. Being more industrialized means that they are more likely to have built up in-house competence in implementing and operating manufacturing technologies and improvement initiatives in general. By having a more industrialized manufacturing facility, these companies are also more likely to benefit from standard solutions. In addition, an increasing number of vendors are offering automation and IT solutions tailored to non-repetitive manufacturing environments (Foehr *et al.*, 2015).

No significant difference regarding the implementation level of technologies for vertical and horizontal integration among the different production environments was found, rejecting *H2.* While earlier research (e.g., Stavrulaki and Davis, 2010; Gosling *et al.*, 2015; Mello *et al.*, 2017) has suggested that companies producing complex customer orders seemed to lag behind regarding the integration of their IT systems, our findings did not replicate these findings. The findings rather indicated that the levels of IT integration across different production environments were similar. Zennaro *et al.* (2019) pointed out that recent studies on one-of-a-kind manufacturing have put a large emphasis on integration tools and information sharing systems. For instance, Mello *et al.* (2015) present an example of a ship manufacturer that integrated its vertical value chain from engineering to production. Furthermore, manufacturers of configure-to-order products increasingly offer product configurators that are integrated with their enterprise systems (Verdouw *et al.*, 2010). Our findings, which show no significant difference in IT integration across different production environments, might indicate that such solutions have started to become mainstream. Several factors might explain this. First, whereas non-repetitive manufacturers previously had to adapt IT tools designed for more repetitive environments (Adrodegari *et al.*, 2015), recently, an increasing number of systems tailored to fit the requirements of non-repetitive manufacturers are available (Tenhiälä *et al.*, 2018). Second, as a growing number of actors in industrial supply chains are adopting enterprise systems and seek to obtain an integrated supply chain (Chiarini *et al.*, 2020), manufacturers are indirectly pressured to adopt such systems to remain a viable supply chain partner. Furthermore, manufacturers of one-of-a-kind products observe increasing demand from customers to track the status of their order (Pero and Rossi, 2014), which is greatly simplified through integrated enterprise systems and can be a motivator for implementing such solutions. Finally, as non-repetitive manufactures are also adopting computerized manufacturing systems and are increasing their IT competency, the benefit of adopting different technologies for vertical and horizontal integration becomes greater as the number of available data points is increased. This might be another explanation as to the wide adoption of integration solutions across the industrial spectrum.

Regarding the differences among production environments concerning the level of organizational IT competence, no significant difference was found. This differed from our initial hypothesis, where we expected that repetitive manufacturers' longer experience with automation and IT solutions would be reflected in their IT competence. Several factors might explain this difference. IT is used in all segments of a business these days, from engineering and design to marketing and customer relations, and it is vital for all production environments. Furthermore, it has also been pointed out that also ETO companies see the need to increase the level of automation of their production processes, material handling, and transportation of materials and equipment in order to remain competitive (Sjøbakk et al., 2014), and the first step is thus to build up relevant competence in their organization.

Finally, it should be noted that while the typology developed by Jonsson and Mattsson (2003) is arguably the most comprehensive for categorizing different production environments (Buer *et al.*, 2018b), there have been significant technological and manufacturing systems developments since this typology was published. It should thus be noted that a potential future production environment typology, which incorporates such developments, may uncover implementation level differences in today's complex industrial landscape more accurately than that of Jonsson and Mattsson (2003).

5.2 The impact of company size

Although the impact of production environments was non-significant, company size was a significant predictor for two of the investigated digitalization aspects. Both for shop floor digitalization and organizational IT competence, LEs had a significantly higher implementation level than SMEs. Next, the results from the testing of the hypotheses related to company size will be discussed in detail.

The results from the survey confirmed that LEs have a significantly higher level of shop floor digitalization than SMEs, confirming *H4.* These findings thus support earlier propositions by Malekifar *et al.* (2014) and Mittal *et al.* (2018), among others, which expressed concerns that SMEs may lag behind in the increasing digitalization of manufacturing operations. Although component prices are decreasing, it is well known that building up and maintaining an IT infrastructure is a costly investment. Every production system is unique, and it requires significant effort and expertise to transform it into a digital production system that can handle all of the complexities inherent in the production processes. The lower score of the SME group in organizational IT competence might also explain why they lag behind in shop floor digitalization. As the trend of Industry 4.0 is largely vendor-driven, moving toward a digitalized factory requires close collaboration with hardware and software vendors, since there are few off-the-shelf solutions for implementing emerging technologies in manufacturing. The market for such technologies is not saturated (European Commission, 2017), and vendors can direct most of their efforts towards LEs that have larger financial resources. Significant financial investments are needed to collaborate with vendors on implementing and operating new technologies, which may explicate the lag in shop floor digitalization of smaller companies.

Regarding the difference in the implementation level of technologies for vertical and horizontal integration between LEs and SMEs, no statistically significant difference could be found, nor were there any indications of it ($\eta^2 < 0.01$). Earlier research argued that SMEs typically had simpler organizational structures, which meant that they saw no need to implement integrative enterprise systems (Buonanno *et al.*, 2005; Li *et al.*, 2006). However, our findings suggest that SMEs are now integrating their IT systems, both internally and externally, to the same degree as LEs. This may be due to several factors. First, industrial supply chains are becoming increasingly globalized, with supply chain actors spread across the world. This trend is also the case for SMEs (European Commission, 2015). As such, the increasing complexity of such supply chains necessitates supportive software to facilitate supply chain coordination. There might also be requirements from supply chain partners to integrate into their existing supply chain management systems, which is a motivator for adopting such technologies. Second, an increase in both the number of IT vendors and SME-targeted enterprise system solutions (Jha *et al.*, 2018) is another factor that has enabled and may explain the increasing diffusion of integration technologies in SMEs. This includes a variety of cloud-based solutions that potentially mitigate financial barriers for implementing and operating such systems in SMEs (Salum and Rozan, 2016).

Concerning organizational IT competence, a significant difference was observed between SMEs and LEs. LEs typically have dedicated IT departments and, in some cases, separate research and development departments, which are facilitators for developing Industry 4.0-related capabilities. Financial strength might be another explanation for LEs being able to seek expertise outside of the organizations regarding Industry 4.0-related topics. The finding that SMEs lag behind in this aspect thus confirms the propositions of earlier research (e.g., Arendt, 2008; Bublitz and Noseleit, 2014; European Commission, 2015). As a response to SMEs falling behind in the digital race, the European Commission has recently announced that the upcoming research program Digital Europe will have a particular focus on building digital capabilities in SMEs (European Commission, 2018).

6. Conclusion

To survive in the competitive, global market, organizations are forced to innovate and improve their business models and processes continuously. Digitalization and technologies associated with Industry 4.0 promise to bring disruptive changes to manufacturing and those who are not capable of reaping the new opportunities are predicted to fall behind their competitors. However, there are still open questions regarding the universality of emerging digital manufacturing technologies. The findings of this paper indicate that a company's size is a more significant predictor of digitalization than its production environment. To ensure the survival of manufacturing SMEs in the future, it will, therefore, be essential to direct attention to supporting the digital development of such enterprises.

6.1 Contributions to theory

This paper has presented results from a cross-sectional survey that investigated the usage of digital technologies as well as critical organizational enablers across a broad range of manufacturers. As there is a lack of established measurement instruments for these aspects, we proposed and adapted a measurement instrument that reflects many of the facets of digitalization. We argue that the adaption of this measurement instrument presents a contribution in itself, as this can be used in similar studies in the future, as well as enabling cross-national comparisons.

The results of this study offer several valuable insights into the implementation patterns of emerging digital technologies. This paper presents one of the first studies to investigate differences in the implementation level of emerging digital technologies associated with Industry 4.0 across the industrial spectrum. While there have previously been similar studies investigating the diffusion of, for instance, ERP systems or automation solutions, the dynamic nature of IT implies that such studies should be updated regularly (Ghobakhloo and Hong, 2014).

Motivated by propositions from existing research, we hypothesized that the production environment would be a significant predictor of the implementation level of different aspects of digitalization. However, our survey data did not lend support to these hypotheses. In contradiction to propositions from existing theory, neither the level of shop floor digitalization, technologies for vertical and horizontal integration, nor organizational IT competence strongly depends on the type of production environment. As non-repetitive manufacturers are becoming increasingly industrialized, they are building up organizational competency to develop, operate, and maintain various IT solutions for both administrative and manufacturing processes. Furthermore, more vendors now focus on the large, untapped market of offering automation and IT solutions tailored to non-repetitive production environments. As such, the non-significant difference in the implementation levels of shop floor digitalization and technologies for vertical and horizontal integration might be explained by three aspects, namely, the increased industrialization of non-repetitive production environments, a lack of significant difference in organizational IT competence, and the increasing availability of tailored automation and IT solutions.

Some researchers have prophesied that the digitalization trend will only be beneficial for the LEs. This study contributes to testing this common opinion and lends support to it regarding two out of the three digitalization aspects investigated, suggesting that company size is a key factor in predicting the level of shop floor digitalization and organizational IT competence. SMEs have fewer employees, smaller budgets, and do not typically have dedicated research and development personnel. Therefore, SMEs have less opportunity to enact larger digitalization initiatives and develop related competencies, which may explain their lower levels of IT competence.

The lower IT competence in SMEs may also be an explaining factor as to why SMEs are lagging behind in shop floor digitalization. Few standard solutions for shop floor digitalization exist, and significant effort and expertise are required to tailor such systems. It is also easier for LEs to take the associated financial risks. In addition, SMEs have difficulties seeking outside expertise in shop floor digitalization due to financial barriers. Vendors typically focus on LEs with larger financial resources instead of SMEs, as the market for such emerging solutions is far from saturated.

The implementation level of technologies for vertical and horizontal integration, on the other hand, was not found to be dependent on company size. In contrast to shop floor digitalization technologies, enterprise systems (e.g., ERP systems) are more technologically mature. Such systems are now widespread in LEs. As this market has become saturated, an increasing number of vendors now focus on delivering enterprise systems solutions directed towards SMEs – along with support in the implementation and operation of the systems. The solutions are tailored to the needs, competencies, and financial level of SMEs. This might explain why the lower organizational IT competence in SMEs does not seem to be a major barrier to the implementation of technologies for vertical and horizontal integration.

Knowing the nature of the implementation patterns, as presented in this paper, is important to guide future research efforts. This includes research efforts to assist environments that are currently lagging behind in their digital transformation and to develop implementation frameworks that consider the characteristics of different production environments.

6.2 Managerial implications

This paper has extended the knowledge regarding the relationships between digitalization and production environment and company size, respectively. Although implementation level is different from applicability, our findings provide indications for managers regarding which digital technologies are more applicable in which specific environments. Furthermore, managers can use the survey instrument and the associated results to benchmark themselves against other companies with similar characteristics.

In contrast to earlier studies, this study found that the implementation levels of the investigated digitalization aspects do not strongly depend on the type of production environment. Seeing as these aspects are less context-dependent than previously suggested, managers should be motivated to investigate the possibilities offered by emerging technologies. Companies outside of the industrial spectrum typically associated with extensive use of AMTs and robotic systems may benefit from certain emerging technologies.

This study confirms that SMEs are lagging behind LEs both in terms of shop floor digitalization and organizational IT competence. As the successful implementation of emerging IT solutions might build a competitive advantage and ensure sustainable operations, public policy should address this opportunity through, for example, initiating relevant research programs. Managers in SMEs should seek out such possibilities to increase the IT competence of their organization, both through research projects and participation in knowledge-sharing networks. We further suggest that managers in SMEs start with smaller and simpler IT projects to familiarize themselves with the possibilities, requirements, and challenges from emerging technologies, as such projects come with lower risk.

6.3 Limitations and future research

Some limitations of this research should be noted. When using self-administered questionnaires to gather data, there are risks associated with the respondents not understanding the question or under- or overestimating their actual implementation level. Although the measurement instrument was developed with this in mind, with clear descriptions of all questions, this limitation should be noted. Although our sample size is somewhat smaller than some of the prominent studies in this field, it is still within the recommendation of Hair *et al.* (2010), which suggests that the sample size of each cell of the research design must be larger than the number of dependent variables. Meyers *et al.* (2006) point out that there is no minimum requirement for the sample size for an ANOVA test, as the significance is influenced by the size of the group differences. Furthermore, the sample was comprised of only Norwegian manufacturers. Though we expect these results to hold for manufacturers in other developed countries, we cannot claim with certainty that this is the case. The perception of what digitalization is might change over time, depending on new developments and trends. The measurement instrument used here reflects the current state of the art in industry, but it should be kept in mind that this will likely change in the coming years.

Due to the dynamic nature of IT, with rapid developments and new solutions proposed regularly, we see the value of follow-up studies to determine if the relationships investigated in this study will change over time. This includes studies mapping the implementation levels of some of the most advanced technologies associated with Industry 4.0. Due to a limited number of responses in this study, this study must be mainly positioned as an exploratory study. A future research opportunity is thus to seek empirical validation of these results in a study with a larger sample. As this study did not identify any significant difference in the implementation level of the digitalization aspects among different production environments, some directions for future research emerge. First, measuring production environments on an item level rather than a construct level can give a more contemporary and precise reflection of the company's actual production environment. An example of such a mapping can be found in Buer *et al.* (2018b) and may give more detailed insights into the implementation patterns of different digitalization aspects. Furthermore, future studies should investigate whether factors such as the level of competition in the sector, the company's tier within its supply chain, industry clockspeed, and the degree of technology-focus in the company, sector, and industrial competitors may explain implementation level differences. Future research should also include more detailed studies on how technology can be best applied in different production environments with different requirements. Additionally, we see that SMEs seem to lag behind the LEs when it comes to digitalization. Future research efforts should investigate how digitalization can also benefit this group of companies, which represents 99% of all businesses in the EU (European Commission, 2008).

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Appendix. Descriptions of the four types of production environment included in the survey instrument (Adapted from Jonsson and Mattsson, 2003)

Production environment	Description
Complex customer order production	This type of production implies a low volume, low standardization, and high product variety type of production. The most characteristic feature of this production environment is that the products are more or less designed and engineered to customer order (i.e., it is an engineer-to-order type of operation). Manufacturing batch sizes are typically small and equivalent to the customer order quantity. Products are complex with deep and wide bills of material. The manufacturing throughput times and the delivery lead times are long.
Configure-to-order production	The products produced in this environment have less complexity and are assembled in small batches, based on what kind of customization the customer wants. It can be characterized as an assemble-to-order or make-to-order type of operation, where many optional products can be configured and manufactured by combining standardized and stocked components and semi-finished items. The number of customer orders is rather large and the delivery lead times much shorter than for *complex customer order production.*
Batch production of standardized products	This environment can mainly be characterized as make-to-stock of standardized products in medium- to large-sized quantity orders. These products are typically more complex and have a longer lead time than *repetitive mass production.*
Repetitive mass production	In this production environment, products are made in large volumes on a repetitive and more or less continuous basis. It involves standardized products made or assembled from standardized components characterized by having flat and simple bills of materials.