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A Conceptual Model for Deploying E-Service in SMEs through Capability Building: A Comparative Case Study

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Abstract

This paper proposes a conceptual implementation model for small and medium enterprises (SMEs) to follow as part of their digital transformation. The conceptual model can be translated into a practical step-by-step guide for SMEs to apply during their digital transformation. The model is based on gradually developing industrial capabilities that can influence production processes performance. We employed a comparative case study approach to capture the lessons learned by SMEs in their journey to develop and implement a production digitalization system for deviation management and performance improvement. The model was validated in the cases of study capturing the actual SMEs' needs. Managerial capabilities of production processes such as monitoring and control demonstrate to influence the performance positively. The proposed model aims for a full digital transformation by following a gradual approach to being resource-efficient and integrating their business needs. This paper is an extension of work originally presented in APMS 2020, IFIP AICT 592.

Keywords: Managerial Capabilities, SME, Sustainable Production, Digitalization, Manufacturing Industry

1. Introduction

The main motivation of Industry 4.0 (I4.0) is the connection and integration of manufacturing and service systems to provide effectiveness, adaptability, cooperation, coordination, and efficiency [1, 2]. The concept is based on the emergence of new technologies that enable production to operate in a flexible, efficient, and greenway with high quality at low cost [3, 4]. Such technologies should advance the transmission of information throughout the entire system, and thereby enable better control and operations to be adapted in real-time according to varying demand [5]. The concept is widely spread around the world, given that incorporating emerging technical advancements can improve the industry's ability to deal with global challenges [4]. Studies on I4.0 models that include organizational, business, and technological advancements focus mostly on Multinational Enterprises (MNEs) [6].

Only a few studies specifically focus on supporting SMEs' advancement and shift towards "Smart Manufacturing (SM)" or "I4.0" [7, 8]. SME's perspective has not necessarily been taken into account in terms of outlining the appropriate I4.0 guidelines and industry policies [6, 9] even though they form the backbone of the European Economy.

The technological solutions are often defined as nine elements referred to as "foundational technology advances" i.e. big data and analytics, simulation, autonomous robots, internet of things, cyber-physical systems (CPS), cloud computing, virtual reality, machine-to-machine communication, and cybersecurity [14]. A common practice for researchers and practitioners tends to be treating the technological solutions as standalone elements [5, 10–13]. However, to achieve a successful transformation, I4.0 as a whole should be well understood and a clear road map is to be generated and implemented [9]. Research indicated that larger companies can achieve the higher maturity levels in technology for the I4.0 concept quicker than SMEs given that they can invest more resources i.e. money, time, and technical expertise. On the opposite, an advantage of SMEs against big companies is the lower complexity of their business and manufacturing processes, which translates into smoother and faster implementations [10]. I4.0 projects driven by SMEs often remain cost-driven initiatives [5, 11] and to this day there is no evidence of real business model transformation [5]. Empirical cases in research are frequently centered around presenting single applications, emphasizing the low-cost factor as a main advantage and strength of their application [3, 12–17]. The implementation of the I4.0 concept implies a major challenge which is resilience and robustness of the production system, which is the ability to absorb manufacturing disturbances without failing or breaking and be able to adapt to major variations and gradually return to its original state or "normal" state and level of performance [18, 19]. When trying to connect production processes disturbances and deviations to I4.0, the terms are assessed in works that address resilience and robustness [18, 20, 21], they often focus on (a) analyzing the variation and its adjustability, (b) analyzing variation in terms of disturbances' propagation and their effects which leads to (c) concentrating on the characteristics necessary to build resilience. The term deviation relates to quality and design and it is stated merely as a variation in the physical product specification.

The new technological advancements enable a new array of production process capabilities, which according to [22] can be grouped into four areas: monitoring, control, optimization, and autonomy. These capabilities and technical resources available to achieve the performance targets relate closely. Given the four capabilities, little is understood about how SMEs can develop each one of them to achieve the ultimate goal of autonomy and in what way they can influence the production performance.

SMEs struggle to cope with external market uncertainties and changes, and often taking the next step in increasing or adjusting their business is constrained by lack of expertise and resources [11, 23], yet they need to remain competitive to survive. For that reason, the focus needs to be on understanding the adoption of new technologies as a support for improving deviation handling and developing SMEs' managerial capabilities with a long-term approach.

To contribute to knowledge building within the area, this chapter is centered on the main research question — how can SMEs conduct a digital transformation that supports and aligns with deviation handling for production system performance improvement? A conceptual model that connects the mentioned elements and illustrates the digitalization deployment for SMEs, which to the best of our knowledge is lacking will be validated in the results.

2. Development of production processes under the Industry 4.0 paradigm

I4.0 is expected to generate a great number of benefits such as improved innovation capability, easy monitoring, and diagnosis of system multifunction, increased self-awareness and maintenance capabilities of systems, high productivity with environmentally friendly products, improved flexibility with decreased costs, unbiased, real-time, and knowledge-based decision making [24]. Likewise, emerging technologies are designed to support the processes behind those benefits [25]. Even though they may be applicable in diverse industries, those technologies can generally not be adopted as independent components, they require high management involvement and support to succeed. It is also important to understand the settings of technologies being adopted, the extend of the technology adoption, whether incremental or radical [26, 27], and the environment that will be improved by those technologies i.e. system, process, or activity. SMEs in particular, may not be aware and understand the capabilities required from management to implement such technologies.

Absorbing manufacturing disruptions and adapting is a crucial characteristic to reach with the support of the I4.0 concept and component implementations. In [18, 28] highlight the fact that robustness and resilience may not necessarily concur, but together provide production systems with a sustainable competitive advantage. Previous research [29, 30] has shown that for achieving sustainable production it is crucial to measure performance efficiently, which demands more automatic collection and management of data.

Research on the propagation of disturbances makes a clear distinction between resilience and a robust system [18]. According to [21], resilience is a competitive approach, and robustness is one of the characteristics of resilience. One common aspect presented in the mentioned studies is the variation analysis in the production processes and operations. They agree upon controlling and stabilizing variation to reduce disturbances and deviations. Nevertheless, the range is closed to product variation, which is far from the goal of full integration with the I4.0 transformation. Six characteristics to achieve resilience in I4.0 are identified by [21], these are flexibility, diversity, connectivity, knowledge, redundancy, and robustness. Yet, models and guidelines on how this can be achieved in practice are lacking.

In an analytical framework presented in [5] managerial capabilities [22] are connected with the concept of I4.0, and new technological advancements are represented as means of implementation. Their analytical framework specifies the importance of classifying I4.0 elements in terms of the desired performance objective i.e. flexibility, cost reduction, delivery time reduction, improved productivity, improved quality, and the corresponding managerial capacity that needs to exist. It depicts a close link between the performance objectives, the levels of managerial capability, and the technical resources required for achieving them.

Recognizing the different aspects of digitalization i.e. technical, managerial, and operational will make SMEs more aware of their organizational dimensions like finance, product, process, and people. In return, this acknowledgment will lead to informed decision-making [26], more accurate judgments, and results in coordination with production operations, plans, and supply chains. SME managers must understand the different ways of approaching I4.0. Reflecting on the own company's positioning supports the understanding of how to acquire benefits from this new paradigm [11].

3. A model for digitalization deployment in SMEs

3.1 Research methodology

The research methodology followed in our study consists of three main steps: 1. development of the model, 2. validation of the model integrated into the development of a production digitalization system, and 3. assessment for potential model improvements.

3.2 Development of the model

To build up knowledge on the area we started performing a critical literature review on SMEs digital transformation, frameworks and methods, digital technologies and applications, linked to managerial aspects, performance, and deviation management. Research indicates that analytical models for managerial capabilities exist [7, 10, 24] but still there is a practical approach missing in terms of what structure or sequence to apply and guidance on how to integrate specific performance objectives. For our theoretical model, we adopted the framework proposed by [5] as a foundation, due to the components it envisions i.e. capabilities, means of implementation, and operational performance objectives.

According to [22] intelligence and connectivity enable an entirely new set of product functions and capabilities, which can be grouped into four areas: monitoring, control, optimization, and autonomy. The four capabilities defined initially are linked together, where each capability builds on the next one. For instance, monitoring capabilities are the base for product control, optimization, and autonomy. In that sense, a company will not be able to control and optimize without first having a monitoring system in place. Such a model does not include concrete metrics on the operational performance objectives that SMEs can utilize to track improvement through the development of the capabilities. Our contribution includes the overall equipment effectiveness “OEE” as the initial metric to integrate. The model consists of three main levels 1. Managerial capabilities, 2. Means of implementation and 3. Operational performance objectives. The capabilities are arranged in a proposed deployment order from left to right. Each level and its elements are represented in **Figure 1**.

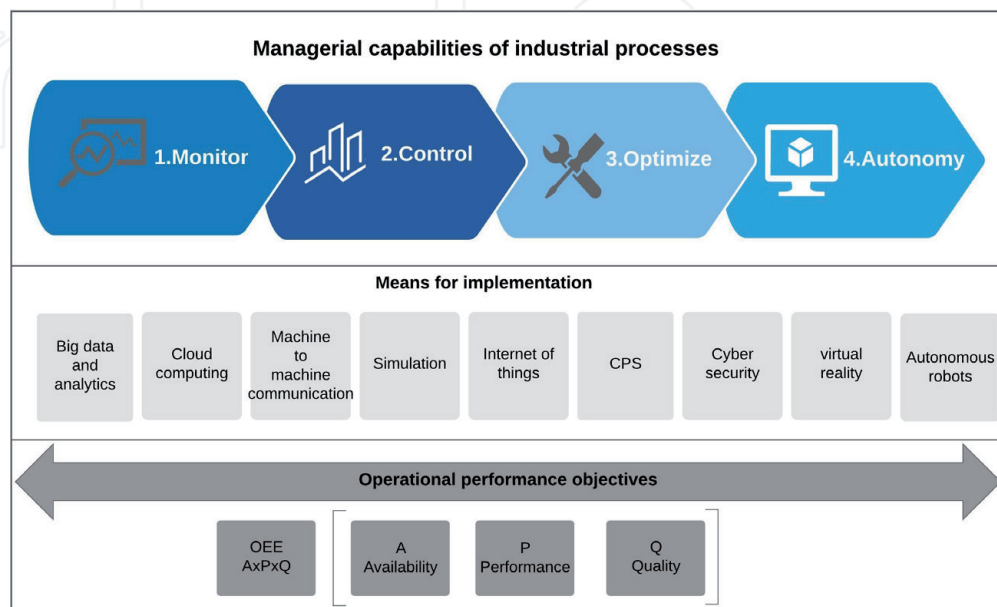


Figure 1. Capability deployment model in SMEs industrial processes based on [5].

According to our research, SMEs are sometimes lacking formal systems to control and measure their performance. That is the reason why we considered the operational performance to be initially measured by the three elements of OEE as key performance indicator “KPI” i.e. availability, performance, and quality. To the best of our knowledge, most SMEs (independent of industry and production strategy), have an initial understanding of the three elements of OEE. Although the OEE data is not always analyzed, the data itself is often generated. Our model aims to change the common reactive practice among SMEs, by proposing a gradual long-term approach that builds on developing managerial capabilities in the production processes.

The introduction of OEE is envisioned as an initial step of the working procedure for SMEs, it is expected to progressively connect to production disturbances improvement and likewise generate positive effects in performance.

3.3 Model validation: practical application on building the managerial capabilities

For validation of the model, we utilized a comparative multiple-study case research approach. This approach was adopted given that case study research is a comprehensive method that incorporates multiple sources of data to provide detailed accounts of complex research phenomena in real-life contexts [31, 32]. The cases in our study are SMEs that decided to take the challenge of internally co-develop a production digitalization system as part of their digital transformation. The context is unique given the innovative approach the company cases have taken i.e. designing and implementing instead of purchasing and implementing an existing system or digital solution. Our data collection consisted of multiple sources such as interviews, observation, notes from physical meetings, and records from disturbances logging. We performed both semi-structured and unstructured interviews along the whole development process. The multiple sources of data with alignment to the results and having multiple researchers (referred to as advisors in the digital system development), who worked in the data analysis guarantee triangulation. Triangulation of data sources, data types, or researchers is a primary strategy that can be used and would support the principle in case study research that the phenomena be viewed and explored from multiple perspectives [32, 33]. The interviews included plant manager, production manager, developers, and operators at both Case A and Case B; this guarantees the elimination of single informant bias.

3.3.1 Practical industrial cases

The cases selected as testbeds for the model are a Swedish SME and a Latvian SME, for confidentiality purposes they will be called case A and case B. Case A has more than 75 years of experience in manufacturing fasteners and industrial components for the automotive and engineering industries. Case B has around 15 years of experience in manufacturing similar components for the Latvian industry and has been considered the largest conical pin manufacturer in Europe. Both cases share experience in manufacturing and belong to the same German-owned corporate group. Their production processes include high-speed cutting, centerless grinding, length turning, tumbling, cylindrical grinding, and centerless grinding. Their production strategy comprises processes from prototyping to serial production.

In 2019, to improve their disturbance handling and become more autonomous, the companies started to join efforts on their digital transformation by collaborating in the development and implementation of a low-cost and tailor-made digital tool, which they call “production process digitalization system”. The project was

interlinked with a research team (advisors) and a couple of students (developers). Before starting this journey both companies had the same Enterprise resource planning system (ERP) in place, representing the only digital solution implemented in their production sites. The system was mostly utilized for production planning purposes. The two cases shared the need for monitoring their production processes more efficiently and integrating real-time data in their ERP-system. Features such as production order completion level, equipment status, and equipment performance were examples of desired information to improve both decision-making and disturbance handling.

3.3.2 The deployment process of the production digitalization system

The development of the digital tool required collaboration at all times since replication of the digital tool was expected. **Figure 2** illustrates the main processes and milestones in the development of the digital tool. The period is indicated to provide a perspective on the length of the project phases. The development can be segmented into four main phases, each one of them with different milestones and processes for each case. At each milestone, both case companies discussed the activities required to guarantee compatibility and feasibility.

The physical development of the digital tool started with building a local network around a system including a programmable logic controller “PLC” and a human-machine interface “HMI” with attached sensors. The local network then was connected to a server that process the data i.e. “means for implementation”. The first physical sensors installation was performed in case A and then replicated in case B (parallel work in phase 3, **Figure 2**). In both cases, data related to OEE was not fully digital, therefore digitizing the data (transferring from manual to digital) was a major initial step to build on the control capability. This digitizing step made it possible to monitor real-time data and helped the operators to start interacting with the system. **Figure 3** is a visual representation of the elements that the prototype tool covers in connection to the capabilities deployment model in **Figure 1**. **Table 1** includes a description of the practical implications of the implemented elements in the cases as illustrated in **Figure 3**.

It is important to emphasize that manual data was a prerequisite to get an overview and an understanding of the environment to develop the tool structure. In this context, “tool structure” refers to the software design and the type of data to collect and display that is relevant for decision-making. Designing the dashboard was part of the collaborative work and conducted parallel to the activities presented in

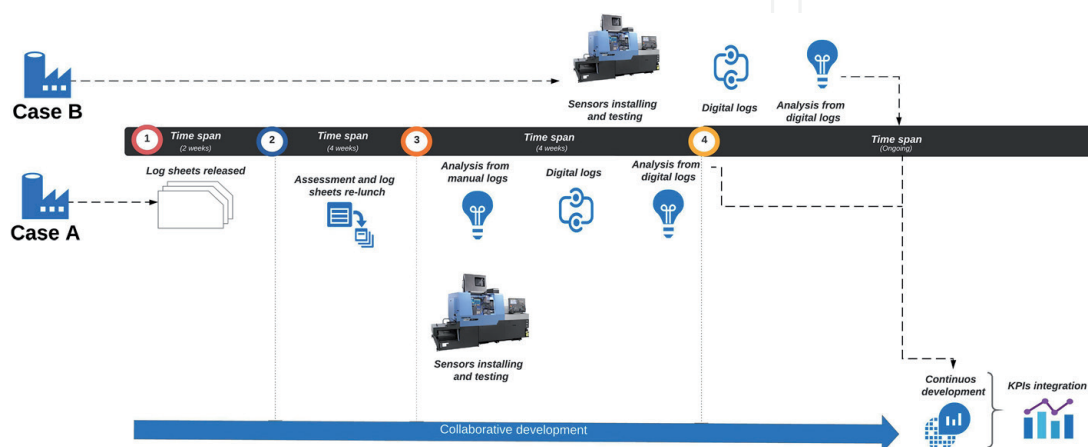


Figure 2. Digital tool development processes and milestones at case A and case B.

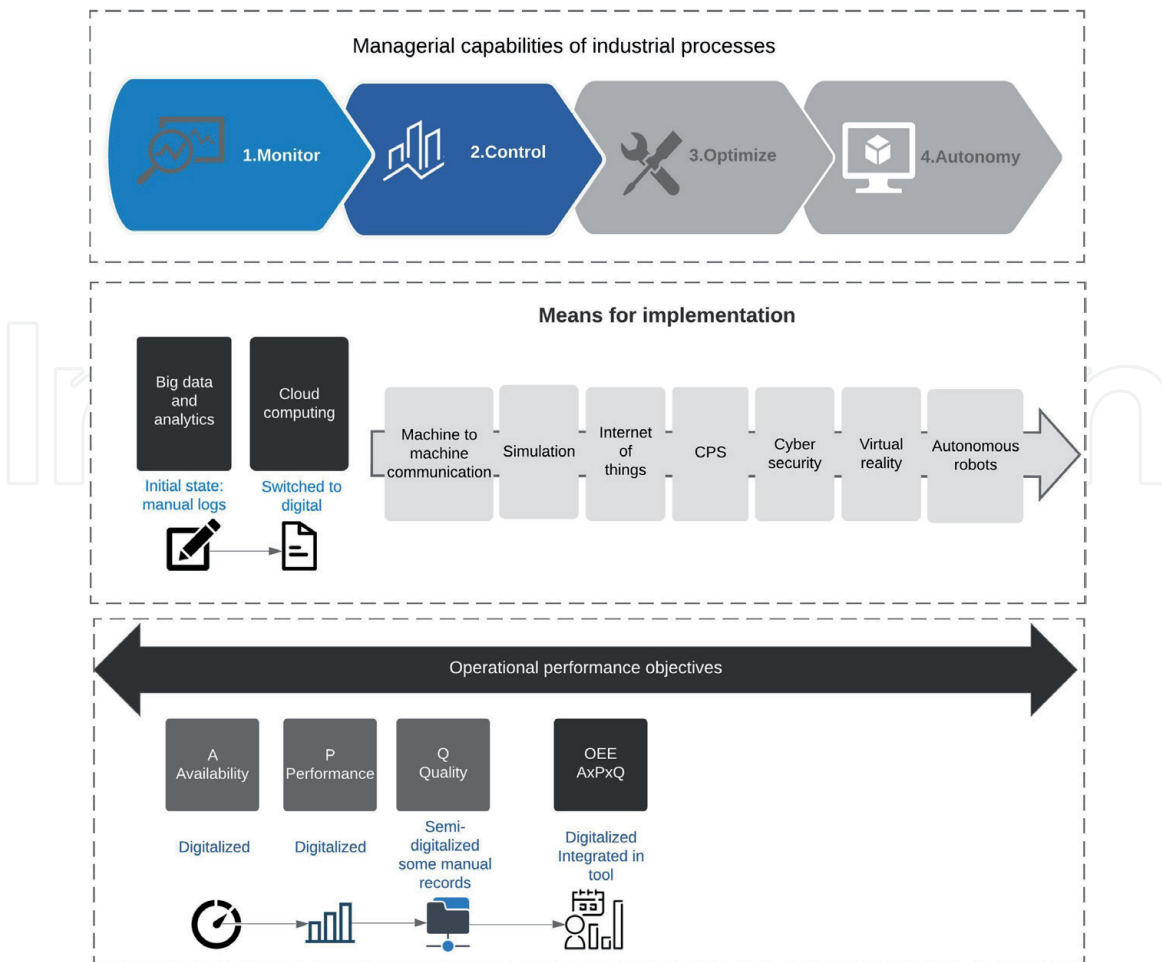


Figure 3.
A demonstration of the deployment of the capability model: from industrial case A.

Figure 2. Figure 4 shows a representation of the original dashboard. The dashboard comprised the following “basic” elements for display in the initial prototype of the production digitalization system:

- Machine number.
- Machine status: A color code indicates status as either a. green indicating normal running machine, b. red indicating stop (planned or unplanned) or c. gray indicating no active production order at the moment.
- Order number.
- Sep-up time: Total time expend on performing set up.
- Quantity: Amount of pieces produced in the displayed time and the total amount in the production order.
- Total time: Amount of time that the machine has been running/producing the indicated production order.
- OEE in terms of Availability (A), Performance efficiency (P), and Quality (Q).

Feedback from the implementation of the tool was collected during the testing phase from operators and managers in both case studies; dashboard upgrading is

Element		Practical details
Managerial capabilities	Monitoring	The starting point of capabilities deployment. Recording of production data, data collection first manually then transitioned to sensors. In about 8 weeks, company case A could migrate to automatic logs.
	Control	Definition of production targets. Utilization of the recorded data. The analysis needed to define improvement thresholds. Introduction of OEE for tracking performance improvement.
	Optimization	Improving by monitoring data, system models, simulation systems, production systems, and resources. The cases have not deployed it at the moment.
	Autonomy	Shifting from reactive behavior to proactive response. The system can learn from the inputs and its behavior and can adapt itself. The cases have not deployed it at the moment.
Operational performance objectives	A: Availability %	Data became available digitally from the machines by installing sensors. Focus on downtime (configurable). The initial data was collected manually by the machine operators.
	P: Performance efficiency %	Data became available digitally from the machines by installing sensors. Focus on cycle times, to reduce discrepancies (configurable). The initial data was collected manually, pre-existing records were in the ERP system but not fully updated.
	Q: Quality	Data is both available from manual records and digitally, depending on the machine. Some quality measures are digitalized but not part of this calculation.

Table 1.
Practical details of the conceptual model elements.

part of the continuous improvement work, together with the KPIs integration. The projection is to have the dashboard accessible online from anywhere so managers and the planning department can access real-time information via their own electronic devices, and for everyone on the production, floor to be aware of the production status at all times. It is expected by the case companies that production disturbances will have a faster resolution since there will be a clear visualization indicating when something is out of control.

The first capability relies heavily on data generation, and the subsequent capabilities are built from it. The importance of data needing to be free from waste and errors is easier to grasp when there is an understanding of the capabilities connection. Also, for a system that is required to be resilient and robust, trustworthy data is vital. We omitted details on the actual OEE calculations, as the focus is to illustrate the initial steps on how to build managerial capabilities with the support from digitalization in manufacturing. Separate work will later assess details on the calculation and integration of OEE in the digital system.

3.4 Assessment for potential model improvement

The model proposed in **Figure 1** was assessed by analyzing the theoretical characteristics and aims against the practical work in the validation stage. The data collected from the cases on the deployment process showed congruency with the theoretical principles and provided some lessons learned that could support and improve the deployment of the model in other SMEs. The summary of the analysis is presented in

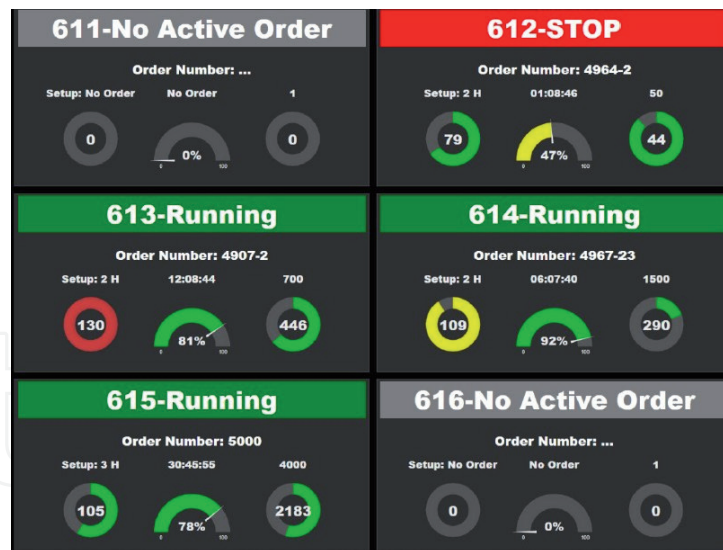


Figure 4.
 An example of the original production digitalization system prototype dashboard.

the analytical generalization in the next section. Further work for model improvement involves investigating the integration of other metrics in the performance objectives and assessing sequence and prioritization of the “means for implementation”.

4. Inspiration for SMEs on starting their digital transformation: recommendations

Our research focused on the SMEs’ need for support to cope with the challenge of remaining competitive in increasingly changing markets. Through the model validation in the real cases, we verified that adopting managerial capabilities of industrial processes supported by digitalization not only provides a competitive advantage to SMEs but also can assist in enhancing the production system performance. The digitalization topic is in a novel field, therefore creating a model that applies to a broad range of manufacturing environments is hard to achieve. Nevertheless, an outcome of the lessons learned from the study cases in this research is the analytical generalization:

- Technologies as means of implementation. The conceptual model calls for a defined sequential deployment journey of the four managerial capabilities. However, it can be inferred that the development and deployment of means of implementation may not follow a compulsory sequence; particularly for the last five blocks: internet of things, CPS, cybersecurity, virtual reality, and autonomous robots (**Figure 1**). The company strategy and business needs may determine the deployment order. For instance, the implementation path for the practical cases in this paper may look different at later capabilities i.e. optimize and autonomy, and even if they agree to replicate the technologies deployment, their progress journey is expected to differ.
- I4.0 elements adaptation. Innovative tailor-made digital solutions could be a safe way for SMEs to progress on their managerial capabilities. The key lays in incorporating the company needs into a digital system that integrates the generated data for processing and analysis purposes to support accurate and quicker decision-making (**Figure 3**).

- Monitor capability with data-hierarchy as the foundation. Given that monitoring highly relies on data, it is necessary to assess what elements are required on the different levels of data processing to ensure generation, transmission, storage, and analysis of data are free of waste and errors. This will contribute to the success of further capabilities deployment.
- OEE as a foundation for a performance improvement system. OEE allows setting realistic thresholds in production to monitor against. This metric is based on production data that most of the SMEs are interested to track and in most cases already generating i.e. availability, performance, and quality. Integrating this metric in digital tools can be an initial step towards performance improvement, giving a good enough overview of any manufacturing site. **Figure 4** presents an example of a visual representation of the system dashboard, which is utilized for monitoring but also controlling production processes performance at all times.
- Resilience and robustness coexisting in I4.0 for SMEs. Robustness is a priority when discussing disturbance and deviation handling. With the introduction of digital tools, SMEs can little by little develop their production systems to have the desired abilities.

5. Conclusion and future work

This study presented a conceptual model for the deployment of digitalization in SMEs, built on the development of four managerial capabilities of a production process. Through real industry cases, a conceptual model was developed, testing the applicability at early stages.

The model suggests a deployment sequence that connects directly to the elements of I4.0 and provides a practical vision on digitalization supporting performance improvement at the factory level by using OEE as the initial metric for the measurement of performance objectives. The industry cases allowed the model validation and the definition of future research to improve the model. This study exemplifies how SMEs with restricted resources can initiate their digital transformation process.

Our research has some limitations. First, given the early stage of the case companies' digitalization journey, only two practical capabilities have been tested. Second, the validation only included two case studies, where the results are described with a qualitative approach and quantitative results are not included. It can be hard to evaluate the real benefits achieved by SMEs developing the capabilities. Therefore, future work will be dedicated to following the evolution of the case companies in achieving the model's higher capabilities (specifically third and fourth), where the priority is to focus on KPIs integration and data-hierarchy. As discussed previously, the resilience and robustness characteristics should be further investigated with a practical approach. It is imperative to build new knowledge that shows I4.0 real advantages for SMEs and ensure the small player's progress on their digitalization journey based on good theoretical foundations.

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Conflict of interest

“The authors declare no conflict of interest.”

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