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A conceptual model for deploying digitalization in SMEs through capability building

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Abstract. This paper proposes a conceptual implementation model for small and medium enterprises (SMEs) to follow as part of their digitalization implementation. It can later be translated into a practical step by step guide for SMEs to practice during their digital transformation. The model is based on gradually developing industrial capabilities that can influence production processes performance. The model development was based on a critical literature review and a real case industry application. The case data served as direct feedback to the model to assess both the model validity and the actual SMEs needs. The capabilities included in the model are proved to directly influence the performance positively. In comparison with existing models and frameworks, this model envisions the company a full digital shift by proposing an achievable sequence which SMEs in a resource-efficient way could start deploying in compliance with their business needs. SMEs can utilize the capabilities as a foundation for a system that supports continuous improvement in the whole factory.

Keywords: Sustainable Production, Managerial Capabilities, Digital Transformation, SME, Manufacturing Industry

1 Introduction

The Industry 4.0 (I4.0) concept is based on the emergence of new technologies so that business process and engineering process are deeply integrated enabling production to operate in a flexible, efficient, and green way with high quality at low cost [1], [2]. Such technologies should improve 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 [3]. The concept is being widely spread around the world, given the trust that incorporating emerging technical advancement can improve the industry's ability to deal with global challenges [1]. However, the SME perspective has not sufficiently been taken into account in terms of framing the appropriate I4.0 policies [4] even though they form the backbone of the European Economy.

The terminology and the so-called nine elements i.e. “foundational technology advances” [5] connected to I4.0 are defined conceptually and treated as single elements both in research and in application [6]–[9]. However, the reality of SMEs positioning in such a context is not clearly defined. I4.0 projects in SMEs often remain cost-driven initiatives and there is still no evidence of real business model transformation at this

time [3]. The practical cases of deployment found in research are often centered around showing single applications, highlighting the low-cost factor as a main advantage and strength of their application [2], [10]–[15].

One major challenge faced by the implementation of the I4.0 concept is the robustness and resilience of the manufacturing production system, that is, the ability to absorb manufacturing disruptions without failing or breaking and to adapt to major variations/disturbances and gradually return to its original level of performance [16], [17]. New technologies enable an entirely new set of capabilities, which according to [18] can be grouped into four areas: monitoring, control, optimization, and autonomy. There is a close relation between these capabilities and the technologies or technical resources available in order to achieve the performance targets. Given the defined four capabilities, little is said about how can SMEs develop each one of them to achieve “self-awareness and autonomy” and how they can connect to production performance.

SMEs might struggle to adapt to external market forces and to make the next step in expanding their business due to a lack of expertise and resources [9]. Therefore, it is necessary to embrace a well assessed and affordable path for the adoption of new technologies that allow them to develop the needed managerial capabilities and create the ability to better handle deviations in their production system. In order to contribute to knowledge building within the area, this paper focuses on a main research question: *How can SMEs conduct a digital transformation that supports and aligns with deviation handling for production system performance improvement?* The results will be demonstrated by a model that connects the mentioned elements and depicts the digitalization deployment for SME; which to the best of our knowledge is lacking.

2 Theoretical background

2.1 Managerial capabilities of production processes

Acknowledging the technical, managerial and operational aspects of digitalization will make SMEs more aware of their own organizational dimensions like finance, product, process, and people. This awareness will result in informed decision making [19], which leads to more accurate judgments and results in close coordination with production plans, operations and supply chains. New technologies are designed to support processes such as data collection, integration, storage, analysis and visualization [20] and they can be deployable in a variety of industries. However, those technologies can generally not be adopted independently, and they require management involvement and support to succeed. It is also important to understand the circumstances of technologies being adopted, the extend of the technology adoption i.e. incremental or radical [19], [21], as well as the system, process or the activity that needs to be improved by technologies. SMEs, in particular, may not always be aware of the understanding and capabilities required from management to implement such technologies.

In a model [3] connect [18] managerial capabilities with the concept of I4.0 (as means of implementation) their analytical model stated the importance of classifying I4.0 elements in terms of the desired performance objective and the corresponding managerial capacity that needs in place. It shows a close relationship between the targeted

objectives, the levels of managerial capacity pursued and the technical resources required to achieve them.

2.2 Disturbance handling as part of the Industry 4.0 paradigm

The ability to absorb manufacturing disruptions and to adapt is a crucial characteristic to achieve with the support of the I4.0 concept and elements implementations. According to [16], [22] robustness and resilience do not necessarily co-exist, but both provide production systems with a sustainable competitive advantage. When trying to connect disturbances and deviations to I4.0, the terms are assessed in works that address resilience and robustness [16], [23], [24], with focus on a) analyzing the variation and its adjustability, b) analyzing variation in terms of disturbances propagation and their effects and that leads to c) concentrating on the characteristics necessary to build resilience.

Research highlights the principle of adjustability as one of the aspects that comply with I4.0 demands when focusing on proactive communication [23]. The deviation is mentioned only as variation in the physical product specification related to quality and design. On their work [16] studies the propagation of disturbances, making a clear distinction between resilience and robust system and highlights the objective of systems for I4.0, which are intended to be robust i.e. have the ability to absorb disruptions without failing or breaking and resilient i.e. have the ability to adapt to major disturbances and gradually return to its original level of performance. According to [24], six characteristics are necessary to achieve resilience in I4.0: flexibility, diversity, connectivity, knowledge, redundancy, and robustness. Resilience is highlighted as a competitive approach, and robustness is mentioned as one of the characteristics for resilience. One common factor presented in the mentioned studies is the variation analysis in the production processes and operations; they all agree that it is necessary to control and stabilize variation to reduce disturbances and deviations. However, the spectrum is closed to product variation, which is far from the aim of full integration with I4.0 or full digital transformation. The characteristics to be resilient may be identified in works like [24], but models and guidelines on how exactly this can be achieved are lacking.

3 A model for digitalization deployment in SMEs

The literature review indicates that analytical models for managerial capabilities exist but there is a practical approach missing in terms of sequence and concrete simplified guidance on how to integrate performance objectives. For our theoretical model, we adopted the analytical model proposed by [3] as a building base, due to the elements it comprehends: capabilities, means of implementation and operational performance objectives. The four capabilities defined initially by [18] are to be linked together, each capability builds on the next one, as valuable in its own right and also sets the stage for the next level. In that sense, a company won't be able to control and optimize without first having a monitoring system in place.

Figure 1 represents the elements in three main categories: 1. managerial capabilities, 2. means of implementation and 3. operational performance objectives. They are arranged in a suggested deployment order from left to right.

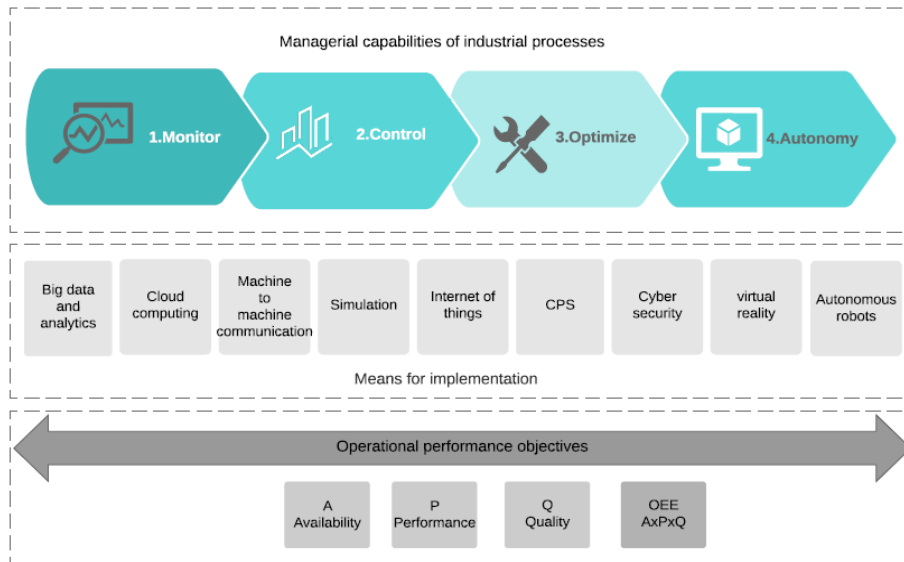


Fig. 1. Model for deploying manufacturing digitalization in SMEs based on [3].

SMEs are sometimes lacking formal systems to control and measure their performance. That was the reason why we considered the operational performance to be initially measured by the three elements of the OEE KPI. To our knowledge, most SMEs independent of industry and production strategy, often have an initial understanding of these three elements. The OEE data is not always analyzed, but that data itself is often generated. With the introduction of OEE as an initial step, a gradual connection to production disturbances is expected, as is the propagation and their effects on performance. A reactive approach is often common practice among SMEs, therefore our model's goal is to make the shift to a proactive approach possible, by developing capability three and four.

3.1 Practical application on the capabilities building

Practical case: A deployment process

The case selected is a Swedish SME with more than 75 years of experience in manufacturing of fasteners and industrial components for the automotive and engineering industries. In 2019, with the objective to improve its disturbance handling and become more autonomous, the company formally started its digital transformation by the development and implementation of a low cost and tailor-made digital tool. The project was interlinked with a research team (advisors) and a couple of students (developers). Table 1 describes the practical implications of the implemented elements in the case

study as illustrated in figure 2, which is a visual representation of the elements that the prototype tool covers. A local network was built around a system containing a PLC and HMI with attached sensors, the local network then connected to a server that processed the data i.e. “means for implementation”. Changing how data was processed (from manual to digital), was a major step to build on the control capability. It made monitoring in real-time possible, and the operators to start interacting with the system. Manual data was initially necessary to get an overview and understanding of the environment to develop the tool. However, for a system that was required to be resilient and robust, that was not enough, trustworthy data was also vital. Due to the length of this paper, we omit details on the actual OEE calculations.

Table 1. Practical details on the conceptual model elements.

Element	Practical details
Monitoring	Starting level. Production data needed to be recorded. The goal was to have the data automatically recorded and avoid human error by manual logs, however, it was necessary to start working with manual data while the sensors were in place. In about 8 weeks, the company migrated to automatic logs.
Control	Aiming to define production targets. Using the recorded data, the company performed an analysis that allowed them to set targets that could be used as comparison points when obtaining new data from the production processes. OEE was introduced.
Optimization	On plan - not deployed at the moment. The goal will be to improve by monitoring data, system models, simulation systems, production system, and resources.
Autonomy	On plan and set as the ultimate goal, when the system can learn from the inputs and its own behavior and can adapt itself. Shift from reactive behavior to proactive response will be enabled.
Operational performance objectives	<u>OEE in terms of AxPxQ</u> A: Availability %. Data became available digitally from the machines (configurable, initial data was collected manually by the operators, special attention on downtime). P: Performance efficiency %. Data became available digitally from the machines (configurable, initial data was collected manually since the only existing records were in ERP system and not updated, special attention on cycle times). 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.

4 Discussion

Being the topic of digitalization in a novel field, it becomes harder to create a model that fits in a higher set of manufacturing/production environments. Nonetheless, the deployment case allows us to offer some analytical generalization as a result of the lessons learned:

- Means of implementation in higher capabilities. The path for deploying the four managerial capabilities in the proposed conceptual model is set systematically and in a defined order. However, we can infer that the means of implementation may not necessarily follow a strict order of deployment, especially for the last five blocks: internet of things, CPS, cybersecurity, virtual reality, and autonomous robots. The deployment order may highly depend on the company strategy and business needs. For instance, a company may decide to prioritize virtual reality for training purposes without necessarily have a CPS in place.
- Adapting I4.0 elements. Taylor-made digital solutions could be a more reliable way for SMEs to develop managerial capabilities. The key lays in incorporating their needs into a digital system that integrates the generated data for analysis purposes to support decision making.
- 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.
- OEE as building base for a performance improvement system. OEE gives a good enough overview of any factory, based on production data that most of the SMEs are interested to track and in most cases already are generating: availability, performance, and quality. It allows setting realistic thresholds to integrate into the digital tools and to monitor against.

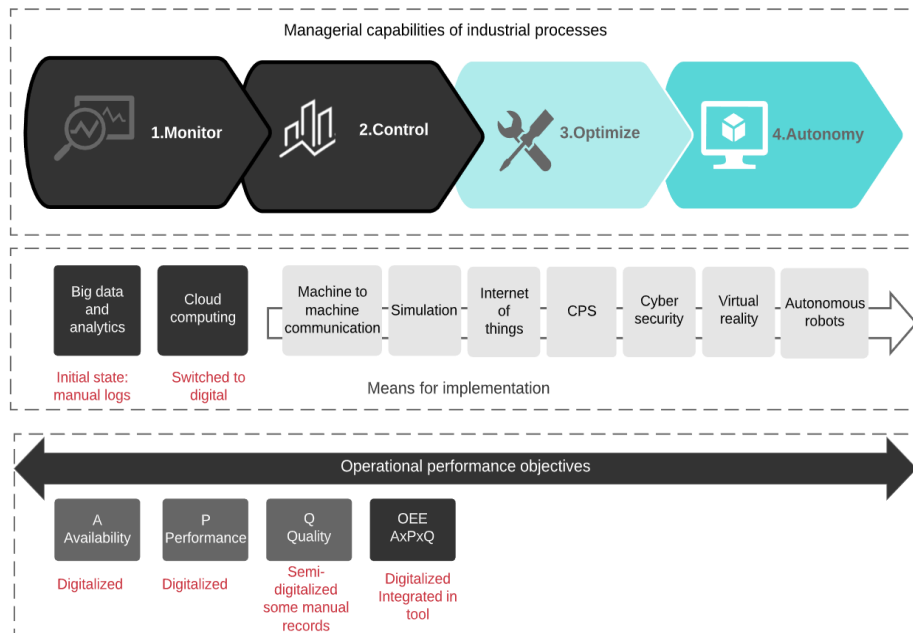


Fig. 2. Exemplification of model deployment: Industrial case.

5 Conclusion and future work

This paper presents a conceptual model for the deployment of digitalization in SMEs, based on the development of four managerial capabilities of a production process. A real industry case was used as base for both developing and testing the early stages of the conceptual model, exemplifying how SMEs with limited resources could initiate their digital transformation process. The model proposes a deployment sequence that connects directly to the elements of I4.0 and suggests the measurement of performance objectives by using OEE as initial metric (KPI). The limitation of the research presented in this paper is that only two practical capabilities have been tested due to the early stage of the company's digitalization journey. Future work could be devoted to following the progression of the manufacturing company in achieving the higher capabilities presented in the model. The characteristics of the practical side when talking about resilience and robustness is furthermore interesting to explore, to build new knowledge ensuring that SMEs build on their digitalization based on a good theoretical foundation.

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