Industrial implementation of an SME-adapted digital tool for monitoring the production: introducing digitalization in small companies

Zuhara Chavez [zuhar@kth.se]
KTH Royal Institute of Technology,
Dept of Sustainable Production Development, Södertälje, Sweden

Jannicke Baalsrud Hauge
KTH Royal Institute of Technology,
Dept of Sustainable Production Development, Södertälje, Sweden

Monica Bellgran
KTH Royal Institute of Technology,
Dept of Sustainable Production Development, Södertälje, Sweden

Alvis Sokolovs
Vidzeme University of Applied Sciences,
Faculty of engineering, Valmiera, Latvia

Abstract

The paper analyses under which circumstances it is possible to develop efficient low-cost-solutions in a small manufacturing company and the impact the introduction of information technology has on developing managerial capabilities of industrial processes. It follows an exploratory single-case study research design. Data have been collected from direct observations, documents such as production orders and log sheets, and semi-structured interviews. It presents an implemented low-cost-solution for supporting an SME in its first two steps of the digitization process. The tool is adaptable and transferable to similar manufacturing companies suggesting that the start of the digitalization process can be heavily simplified.

Keywords: Sustainable production, Digital transformation, SMEs

Introduction

The manufacturing industry is at the beginning of an industrial transformation driven by high demands on sustainability and competitiveness, supported by information technology and new digital solutions (nowadays conceptualized as Industry 4.0). Many production companies have difficulties to follow and sustain the pressure for change (Stoldt et al., 2018). While many companies feel the need for increasing their digital capabilities within production operations, they still face numerous challenges in how to manage this task. This is especially true for Small to Medium Size Enterprises (SMEs), having fewer resources and less competence for digitalization investment. Existing IT-
systems and integrated solutions often represent complex and centrally organized systems, which are costly to adapt and maintain. As a start, they require high investments of capital and technical knowledge that SMEs are lacking, furthermore, they provide high amounts of information that is not utilized and even restrict the integration of IT systems and self-organization of manufacturing processes (Wieland et al., 2016). Smaller enterprises will suffer because of the high investments required, and the increased flexibility introduced by digital solutions will allow bigger enterprises to steal market shares for customized products, a market segment now usually dominated by SMEs (Rüttimann and Stöckli, 2016). In that sense, being the projection that SMEs will fall behind, there is a need to devote research that supports the small players to cope with the ongoing shift.

In Sweden, the SME category accounts for 99.9% of the total companies, many of them are lacking the necessary resources to acquire the available solutions, hindering them from transitioning to digital ways of working. Nevertheless, SMEs are keen to employ new technologies in their factories to raise their competitiveness and improve performance (Stoldt et al., 2018). These efforts will likely result in new managerial and production capacities aligned with the organization’s strategy (Moeuf et al., 2018). Extensive and recent research dedicated to SMEs and Industry 4.0 maturity models, roadmaps, frameworks, technologies and enabling factors confirm that the vision of large enterprises does not fit with the needs of the SMEs (Mittal et al., 2018, 2019, 2020), this gives significance to why develop an SME-adapted digital tool.

The objective of our research is to analyze under which circumstances and limitations it is possible to develop efficient low-cost digital solutions in a Swedish SME, exploring what is the minimal investment in capital and knowledge required. The SME-adapted digital tool is positioned under Moeuf et al. (2018) analytical framework in terms of the managerial capabilities enabled by the prototype i.e. means of implementation. The research furthermore focuses on assessing the impact that the introduction of information technology has on the development of managerial capabilities of industrial processes in SMEs, particularly the monitoring and controlling of production processes. Therefore, the paper is centred on two interlinked research questions: 1. how does a digital transformation look like for an SME with limited resources? And specifically, 2. how can managerial capabilities be developed through digital technologies to enable production process stability and preserve system usefulness to build-up performance in SMEs?

Research Methodology
The paper follows an inductive holistic approach to a qualitative exploratory single-case study. Through the case, the objective is to exemplify how an SME can take its initial steps by developing and implementing the first two steps in digital development (data collection and digital processes) and thus introduce the factory to the digitalization journey. The sources of data come from direct observations field notes, documents such as production orders and log sheets, semi-structured interviews with production workers, and key support roles. In order to strengthen the validity of the research, triangulation was employed to assess both qualitative and quantitative data.

Industrial case description
The case study is a Swedish SME that has more than 75 years of experience in the manufacturing of fasteners and industrial components for the automotive and engineering industries. The company has a functional layout and works under an MTO production policy. Almost all products go through the process of 1) material cutting 2) chamfering,
3) hardening (outsourced when specified by the customer) 4) centerless grinding, and 5) parts check and packaging. Strategically, the process selected to start the prototype implementation was chamfering, which is mostly performed by CNC machines. The company has in use an ERP system “Monitor” which serves mostly for production planning and handling customer orders, other than that there was no other digital solution in place supporting the monitoring and control of production processes. The case illustrates the development and implementation of a low cost, in-house prototype with high data quality and stability by employing rapid SCADA as the software. Due to time restrictions and internal advice, it was decided that integration with ERP Monitor would be excluded. The development of the prototype tool was part of a thesis project in connection to a funded running project, therefore two engineering students were dedicated full-time to the project (10 weeks on development), while co-supervisors and a researcher together with company CEO (all part of the funded project) served as a steering group, and supported on triangulation of information through the development and first implementation phases.

Data collection
In order to better understand the environment in which the system would be implemented, weekly study visits were carried out at the company throughout the entire project’s progress. During these study visits, operators were interviewed as well as other employees who would have any interaction with the digital system. The interviews were vital to form an idea of the demands and requirements the company’s staff had on the system, hence guarantee the solution would cover their needs appropriately. After gathering a general knowledge of the production site and its environment, a log sheet was developed with the support of the company CEO; the stages followed for the tool development including the manual production data collection by the developed log sheets is depicted in figure 1.

![Figure 1 – Industrial case tool prototype development stages](image)

The objective of the log sheet was to capture production disturbances of all types. Operators were instructed to record planned and unplanned stop times for each production order, the figures were to be used in the prototype OEE (overall equipment efficiency) calculations. The purpose of the log sheet for enabling production data collection was to obtain reference values which could later be compared with the production data the future digital system would collect automatically. Furthermore, these measurements would also
provide a better insight into which KPIs could be measured and how these should be measured most effectively. Previous to the log sheets data capture, the company had no reliable digital data about the production output in terms of time, hence no productivity metrics were in place. Through the ERP system the company had only a sense of customer on-time delivery against orders in the system, hence total produced parts. The cycle times in the system were standards estimated that not necessarily fit all the product’s real production times. For instance, there was no distinction between prototype orders or normal production. The company did not have accurate visibility of non-value-added vs value-added time in the processes under their ERP system, neither to say real-time data about the machines running at a given time.

**Theoretical background**

*Digitalization in Small to Medium Size Enterprises (SMEs)*

The accessibility to technologies at affordable prices has positively influenced the operations of manufacturing systems and has enabled the adoption of digitalization from an SME perspective (Ganzarain and Errasti, 2016; Mittal et al., 2020), however, the adoption of technologies is not necessarily done in a purposeful way. For example, increasing the capacity of information systems to store and analyse big amounts of data (Aluet-Garza and Kurfess, 2018). Despite the growing number of new tools and technologies, most of them are under-exploited, if not ignored by SMEs (Kurfess, 2018; Moeuf et al., 2018). In their study, Moeuf et al. (2018) show that applications of Industry 4.0 within SMEs are mostly related to the monitoring of production processes and to the improvement of current capabilities and flexibility. The least expensive and least revolutionary technologies (simulation, cloud computing) are the most exploited in SMEs whereas those allowing profound business transformations (CPS, Machine-To-Machine, big data, collaborative robot) are still neglected by SMEs (ibid.). Collecting production data of production machines and equipment is fundamental to manage and improve production operations. Through their empirical work Mittal et al., (2020) validated the incomplete use of ERP system as a demonstrated example where SMEs possess certain capabilities, but they are not exploiting them to its full potential. The rate at which the data for every feasible process is collected (or can be collected), provides further opportunities to fine-tune the existing manufacturing practices at SMEs (Marr, 2015). The difficulty of data collection is dependent on the complexity of the manufacturing system and whether the data collection is manual or automated. In order to appeal to the SME, there is a need to convert the data related to other organizational dimensions as cost data (Muchiri and Pintelon, 2008). For instance, the data related to the number of hours should be converted as cost/hour, since this could inform the SME managers about the downtime cost (of a machine) (Mittal et al., 2020). This comparison could be translated to other costs such as operators' training cost and maintenance cost, that SMEs managers can utilize to better target the improvements in their business. In their study, Sashi et al. (2019) tested the hypothesis of process innovation (i.e. of new technologies, new processes, new products) positively affecting the financial performance. The results turned out highly positive supporting the fact that due to globalization, the needs for an efficient production system have dramatically changed over the years, pushing SMEs to explore innovation and particularly new technologies. The most common and simple applications are balancing the pace of production with actual demand, thereby restrain the rate of overproduction.
Managerial capabilities of production performance supported by digitalization

Accomplishing performance objectives often requires investments and the use of specific expertise, here defined as managerial capabilities. Transformation efforts will likely result in new managerial and production capabilities aligned with the organization’s strategy (Moeuf et al., 2018). In their analytical framework, Moeuf et al. (2018) connect Porter and Heppelmann’s (2014) managerial capabilities with the concept of Industry 4.0 (as means of implementation). Each capability (table 1) is valuable in its own right and also sets the stage for the next level (Porter and Heppelmann, 2014). In that sense, monitoring is the base for building control, optimization, and autonomy.

Table 1 – Managerial capabilities developed under I4.0 scheme based on Moeuf et al. (2018)

<table>
<thead>
<tr>
<th>Capability</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitoring</td>
<td>Allows for recording data during the entire production process. It can provide several performance indicators.</td>
</tr>
<tr>
<td>Control</td>
<td>It demands man-system interaction. Production data can be used to obtain the performance of different production resources and compare it to predetermined thresholds and/or historical data.</td>
</tr>
<tr>
<td>Optimization</td>
<td>Allows improvement by monitoring data, system models and simulation systems, production systems, and resources.</td>
</tr>
<tr>
<td>Autonomy</td>
<td>The systems become capable of learning autonomously from their own, behaviour and adapts itself.</td>
</tr>
</tbody>
</table>

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 (Mittal et al., 2019), which leads to more accurate judgments and results in close coordination to production plans, operations, and supply chains. The structured process of data collection, integration, storage, analysis, visualization, and application is generally applicable and deployable for a variety of different industries (Tao et al., 2018). New technologies are designed to support those processes, however, technologies can generally not be adopted independently. It is also important to understand the circumstances of technologies being adopted, the extend of the technology adoption i.e. incremental or radical (Mittal et al., 2019; Stoldt et al., 2018), as well as, the system, process or the activity that needs to be made improved by technologies.

OEE as an initial measure of production performance in digital tools

OEE is traditionally used by practitioners as an operational measure to monitor production performance, but it can also be used as an indicator for process improvement activities in a production context (Andersson and Bellgran, 2015). OEE proves to be a valuable tool that can help management to unleash hidden capacity and therefore reduce overtime expenditures and allow deferral of major capital investment (Andersson and Bellgran, 2015; Muchiri and Pintelon, 2008; Sohal et al., 2010). It aids in reducing process variability, reducing changeover times, and improving operator performance. It is used as a standalone key performance measurement tool for productivity improvements. OEE has the potential to be transformed into a system for analyzing production data to identify potential areas of improvement and supporting lean initiatives (Sohal et al., 2010).

The variants of OEE such as overall plant effectiveness (OPE), overall throughput effectiveness (OTE), production equipment effectiveness (PEE), overall asset effectiveness (OAE) and total equipment effectiveness performance (TEEP) depend highly on the type of production losses included, therefore the industrial application from one company to another varies (Muchiri and Pintelon, 2008; Ylipäää et al., 2017). OEE is
a very valuable key figure in order to continue developing the factory. There are some aspects that OEE will not display e.g. cost. OEE is not directly linked to profit or costs (Muchiri and Pintelon, 2008), it is only corresponding to where deficiencies can exist in the factory. This can give an unclear picture of what is profitable to do when making decisions about initiating or targeting improvements. OEE is being deployed as an improvement driver once the deficiency of equipment is exposed (Andersson and Bellgran, 2015) but the success of OEE relies on a good data collection system. The quality of data collected determines the accuracy of the OEE calculation. Information provided by the data analysis can provide a basis for performance improvement, monitoring, and control (Cheah et al., 2020), such capacities can be better guaranteed by automated data collection.

The next section will present a case study showing how the implementation of low-cost technologies has an impact on the OEE and how this helps in managing the daily operation.

**Results**
The case includes the development/adaption of a monitoring system with real-time updates of orders, automatic calculations of KPIs, and production data collection, which allow to effectively analysing the company’s processes. By that, it is possible to assess the impact that technology introduction has on monitoring and controlling the production processes.

**Implementation of an SME adapted digital tool: prototype building process**
The goal for the prototype was to be as cost-efficient as possible without risking quality and stability in the data transfer with a limited budget. Hence a local network was built around a system containing a PLC (programmable logic controller) and HMI (human machine interface) with attached sensors. The local network then connects to a server that processes the data that is transferred.

The database is built on SCADA and translates the signals transferred from the PLC and HMI into “easy to understand values”, that can either be used for local utilization or connected to the world wide web for usage outside of the factory. The system-building needed initial hardware listed on table 2, all the items were acquired from the main project budget which estimated cost was no more than 3000 SEK at that time. Selecting a suitable software to work with, was a major decision that guaranteed smooth development. The team selected Rapid SCADA for being an open-source industrial-automation-platform for development custom SCADA and MES solutions. The students did not possess previous specific technical software knowledge but with the information available publicly and expert mentoring, they were able to initiate the design of the prototype. The prototype key software components and their function are described in table 3.

OEE was the first metric to be integrated into the software programming. The numeric production data collected from the case allowed the initial calculations (manual logs), but with real data obtained directly from the machines, these calculations became automatic in the digital tool. It was decided that OEE should be the first KPI to strive for, in order to initiate efforts for tracking and measure performance. For the company case, OEE shows to contain enough elements to track and improve. It also provides the opportunity to, later on, use the measures as a base to build a system to identify potential areas of improvement and support lean initiatives.
Table 2 – Prototype initial hardware requirements and functions

<table>
<thead>
<tr>
<th>Item</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raspberry Pi 3 Model B+ kit</td>
<td>To use as a SCADA server and handle all the data processing.</td>
</tr>
<tr>
<td>USB-memory stick 32 Gb</td>
<td>To use as backup storage for all the collected data.</td>
</tr>
<tr>
<td>TP-link TL-SG105E 5-port switch</td>
<td>To enable multiple inputs on the network and to set up a secondary VLAN.</td>
</tr>
<tr>
<td>Network-cable 4m (2mx2)</td>
<td>To make physical connections.</td>
</tr>
<tr>
<td>Asus RT-AC66U router AC1750</td>
<td>To set up VLAN, DDNS-server, enable multiple inputs and serves as a</td>
</tr>
<tr>
<td></td>
<td>platform for all the network managing.</td>
</tr>
</tbody>
</table>

Table 3 – Prototype software components and functions

<table>
<thead>
<tr>
<th>Key components</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapid SCADA</td>
<td>Captures digital signals from PLC / HMI, where PLC takes in and converts</td>
</tr>
<tr>
<td></td>
<td>signals from one or more sensors. It is installed on an MCU, Raspberry</td>
</tr>
<tr>
<td></td>
<td>Pi, and the network is built with the switch and router.</td>
</tr>
<tr>
<td>Main sub-programs</td>
<td>The software consists of five sub-programs where each program has its</td>
</tr>
<tr>
<td></td>
<td>own task. Three sub-programs are designed for processing and saving data:</td>
</tr>
<tr>
<td>Administrator</td>
<td>All data processed and taken in/out is manipulated by this sub-program</td>
</tr>
<tr>
<td>Communicator</td>
<td>Maintains communication between PLC / HMI and Rapid SCADA, also it is</td>
</tr>
<tr>
<td>Server</td>
<td>Sends out all information from the database to the network. It is only</td>
</tr>
<tr>
<td></td>
<td>required to select the location for the data and layout to be sent out,</td>
</tr>
</tbody>
</table>

Analysis

The initial version of the prototype possessed the capabilities of monitor and control (early stage) by utilizing data analysis and cloud computing. Visual representation in connection to the conceptual model is presented in figure 2. For this study, we have excluded the full connection to operational performance objectives, because of the early stage of the prototype and due to the case not possessing KPIs calculation records. OEE is utilized in the prototype, as the base for building performance objectives. It is intended to gather enough production data for picturing the factory current state as a starting point, and from there establish feasible targets for improvement.

The studied company runs orders in large quantity which means that normally, an order will remain for more than one day in a particular process/station. Given the condition of having a well-functioning digital system, the company would be able to continue its operations with fewer employees if desired or by increasing the competence of each operator. The possibility for operator mobility is facilitated by the monitoring system. When the operator understands how digital technology works, reports of deviations become more autonomous and in real-time (Svinge and Andreas, 2019). Also, management can make faster decisions trusting the information displayed in the digital tool is accurate and reliable; this characteristic is applicable to other working environments with multiple changeovers or running small batches. With the tool, using the system's self-regulation machines enable the company to provide real-time information and status on their orders; which personnel at different levels can use to obtain information about production resources and have a visual status on breakdowns and production orders. Such information enables taking accurate decisions, prioritize better, and assign assets properly. Having a well operating and reliable digital system was
proved vital and emphasize the importance of trustworthy data to enable the use of information for monitoring and metrics control for accurate decision-making and to guide improvements.

![Managerial capabilities of industrial processes](image)

**Figure 2 – Prototype positioning. Adapted from Moeuf et al. (2018) analytical framework**

**Discussion**

SMEs face numerous challenges on daily operations, increasing their digital capabilities within production operations may be a way to bring up the factory performance and manage the risk that a digital transformation implies. Explicitly, SMEs should focus their efforts on what information they need to be able to develop individual processes and create a basis for gradually developing their digital factory which helps to develop the real factory by the realized capabilities utilization.

The importance of having a functioning digital system has clearly proved important in the studied case company. Measuring manually is not only time consuming, but it also lacks accuracy. After the production data collection phase with the manual log sheet, it became apparent that the measured values were not strong enough to be able to draw a conclusion on how the factory performed but it gave great insights about the “real” production results in comparison to “planned” numbers existing in the ERP system. As mentioned before, OEE has a very good value to envision what improvements need to be made in the factory to increase the performance with the resources available. It also provides a base to expand to other metrics or create a system aligned with lean, when OEE has matured within the company. The validity and worth of OEE as a metric was proved highly dependent on the production data collection and accuracy. By implementing digital systems the accuracy is expected to increase. Such increment can seem obvious in comparison with manual logs. However, it is necessary to highlight the value of starting with manual logs to initiate the development and create a clear understanding of how the production system behaves. This understanding will support the creation of a user-friendly and reliable tool that meets the company-specific needs. Some analytical generalizations as a result of the lessons learned from the case study are for example:

- **Balance potential human error and system complexity:** system capabilities call for man-system interaction, as it may be required either handling specifications or input data in the system. The simpler the design often turns on more human
involvement (on analysis, processing, or simple data entering) that may translate on human errors that can reduce the data accuracy. A more sophisticated system may increase accuracy but at the expense of increasing complexity; such complexity can translate in further costs e.g. technical skills development, systems compatibility, etc. SMEs need to assess the trade-offs between the two paths.

- **Building blocks for future system expansion**: a recommendation for SMEs is to have a road map than envisions a potential overall digital transformation, and think of the initial steps as the building-base in form of blocks than can be either modified or added on top for a gradual deployment. A simple rule is that initial digital efforts should allow for expansion rather than set limits to digitally transform.

- **OEE driving improvement of production performance**: OEE does not provide any cost perspective which is in most cases a decisive factor for SME managers. However, it can give a good enough overview of any factory based on data that most of the SMEs are interested to track and in most cases already generating: availability, performance and quality.

**Conclusion**
This study presented a realized low-cost solution for supporting a small-sized company in the first two steps of digital development (data collection and digital processes). The necessary investment in terms of hardware to initiate an SME on those two steps shows to be at economical reach for SMEs. The challenge becomes devoting human resources to learn and deploy the tool internally. Specifically, in this project, the researchers developed and implemented the necessary for a small factory to automatically monitor their machines and processes. This means a monitoring system with real-time updates of orders, automatic calculations of KPIs, and data collection to effectively analyse the company’s processes and later on deploy fully the control capability. The solution presented here is adaptable and transferable to similar companies, and it opens the possibilities for SMEs on the digital transformation by showing that the focus should be on assessing what information is necessary and then create individual processes rather than acquiring “one size fits all” tool. In terms of budget, the digitalized system does not require large capital investments, but it may take time to learn about the components needed to build it; the researchers suggest that with little expertise, the way to start the digitalization process could be much simplified. In purchased tools, support is in most cases a service provided; therefore the challenges are maintenance, support, and upgrades that the system may call, requiring assigned resources. Ongoing work is dedicated to gathering data and testing the prototype in a different setting for integrating metrics and developing a user-friendly dashboard that allows easy deployment and transferability to multiple company-cases. The project reflects the relevance of the academia-industry contribution. SMEs may lack economic capital to inject directly in investments for digital development but the academy can bring-in the knowledge by conducting empirical research to target the few resources available and integrate the existing human capital in a more efficient way.

**Acknowledgements**
This work is part of the project ASPIRE “Automation solutions for production deviation management”, funded by Sweden’s Government Agency for Innovation VINNOVA (Programme Produktion2030). The authors gratefully acknowledge the funding, as well
as good collaboration and great support from the case company. Special recognition to Carl Svinge and Andreas Farde for the efforts on the prototype developing phases and for allowing the authors to document and share the technical details of their work.

References


Svinge, C. and Andreas, F. (2019), SCADA-system för mindre företag, KTH.

