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Lean first ... then digitalize: a standard approach for Industry 4.0 implementation in SMEs

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Abstract. The digitalization of manufacturing is the essence of Industry 4.0 realization. Many large manufacturers have developed ambitious digitalization strategies, and most have taken the first steps towards digital transformation. Unfortunately, the same cannot be said for small and medium-sized enterprises (SMEs). At the same time, SMEs contribute on average with more than 50% of the value to the economy in the European Union and with almost 100 million employees, represent approximately 70% of the European workforce. This makes the onset of Industry 4.0 and the accompanying digitalization of manufacturing a fundamental challenge for most SMEs, many of which already struggle to remain competitive in a rapidly evolving business climate. As such, in this paper, we aim to present an SME-friendly approach to Industry 4.0 implementation. We share practical insights from three SME case studies that enable us to propose the *lean first ... then digitalize* approach to Industry 4.0 implementation in SMEs.

Keywords: Lean, Industry 4.0, Digitalization, SMEs.

1 Introduction

The digitalization of manufacturing has become a hot topic in recent years. The increased levels of connectivity provided by the industrial internet of things (IIoT) and big data analytics, combined with various methods of exploiting digital twins and artificial intelligence (AI), allows for the realization of so-called cyber-physical production systems (CPSs) that promise to advance the competitiveness of manufacturing organizations [1]. However, several analyses reveal that although most leading manufacturing firms have ambitious plans for digitalization, many of them are far from ready to benefit from it [2, 3]. This is particularly challenging for small- and medium-sized enterprises (SMEs), which are the backbone of the manufacturing sector in many European countries [4], yet typically lack the financial resources, advanced manufacturing technologies, research and development capabilities, and organizational culture required for a digital transformation [5]. [6] also suggests that there is little awareness of *Smart*

Manufacturing (SM) and its related topics among manufacturing SMEs. As such, many SMEs think they are ill-equipped to adopt the SM paradigm [7].

Many of the suppliers to the large manufacturing enterprises are SMEs, and as such, SMEs play a vital role in contemporary manufacturing value chains [8]. They contribute on average with more than 50% of the value to the economy in the European Union and with almost 100 million employees, represent approximately 70% of the European workforce. However, SMEs often lag behind when it comes to innovation – and this can impede industrial growth [9]. [10] presents several characteristics to help explain why SMEs struggle with change management in general, including a firefighting approach to solving problems, a lack of long-term planning, and a command-and-control culture. These are in direct contrast to the three Ls of lean described in [11]: *learning*, *a long-term perspective*, and *leadership*. For this reason, we position lean thinking and practice as a fundamental prerequisite for the successful digitalization of manufacturing, particularly in SMEs.

In this paper, we draw on insights from three industrial case studies to construct an SME-friendly Industry 4.0 implementation process. To guide the investigation, we adopt the following research question (RQ): *How can SMEs implement and benefit from Industry 4.0?*

2 Theoretical Background

2.1 Industry 4.0

There is much written about the benefits that industry 4.0 technologies can bring to manufacturing [12], and equally as much written about how the same technologies will lead to job losses [13]. Whilst this age-old argument remains, further analysis shows that new roles are, in fact, emerging for upskilled individuals. The challenge for SMEs of course, is to create environments where the skills and resources can be developed to capitalize on the potential economic impact that Industry 4.0 technologies promise. This involves boosting interdisciplinary thinking whilst appraising and deploying these technologies from a disciplined lean management perspective. [14] concludes that, whilst SMEs understand that the deployment of Industry 4.0 technologies cannot simply be ignored and that there was a clear desire for companies to begin (or in some cases, extend their levels of engagement), the same companies highlighted uncertainties in understanding both the full potential and the challenges of embracing these technologies.

2.2 Cyber-Physical Production Systems and Digital Lean Manufacturing

With the onset of digitalization, mechanical production systems evolve into cyber-physical production systems (CPPSs). As such, established lean methods gain a new, digitally enhanced edge. This phenomenon has been coined *digital lean manufacturing* [15]. However, such a paradigm assumes that the manufacturing firm has already adopted lean thinking and practice as an alternative means of managing the business. If not, as is the case of most SMEs, then the leap to a digital tomorrow simply risks

automating the wasteful activities of today. As such, lean must also pave the way for effective digital transformation.

3 Research Design

Given the exploratory nature of our investigation and the how-based research question, we adopt case study research to explore how SMEs can implement and benefit from Industry 4.0. We specifically employ a multiple case research design, conducting semi-structured interviews with representatives from the industry 4.0 initiatives of three SMEs in Norway and Wales. The initiatives involve both the focal SMEs and the digitalization partners (contractors / consultants / researchers). Rich data that emerged from discussions with representatives of each of the three initiatives provided valuable insights that were subsequently used to construct the proposed *lean first ... then digitalize* approach to implementing Industry 4.0 in SMEs.

3.1 Case study 1

Case study 1 is a medium-sized manufacturing and engineering support company located in Norway. The company is a contract producer of mechanical products with 21 employees and a turnover of 2MGBP (2019). The company initiated a project in 2020 to identify opportunities for digitalization, with a view to improving information flow within and across the firm's operations. The project was implemented over a three-month period, which included several workshops with the company.

Following an initial tour of the company's facilities, it became apparent that the company could benefit significantly from adopting basic lean thinking and practice – prior to any adoption of digital technology. For example, it was suggested that the company investigate lean production as a means of improving its operational performance, as well as lean leadership to help develop the continuous improvement culture required for successful lean- (and eventually digital-) transformation.

During further interventions with the SME, it was also observed that operators and employees relied heavily on paper-based work instructions and printed technical drawings and control plans. On further discussion, it became apparent that operators were often uncertain as to whether the documentation they were working from was the correct and current revision. As such, it was suggested that the company consider digitizing various analogue information, through the provision of tablets to the operators at the workstations, such that drawings and technical documentation could be stored online, readily available, and updated in near real-time.

The final stage in the digitalization project, and the first tangible effort for digitalization, was the suggestion of greater horizontal and vertical system integration. Here, the intended solution was to simply adopt a readily available digital collaboration platform (e.g., Microsoft Teams) to foster inter-organizational collaboration and improvement between the focal firm and its customers.

3.2 Case study 2

The second case study draws upon work carried out at a South Wales based materials and casting company. The company produces high-value components for a range of sectors, including aerospace, automotive, and food and drink. With 211 employees and a turnover of 31MGBP, the organization predominantly utilizes foundry and machining processes to produce components for their wide-customer base. In 2019, the company began to explore opportunities for increased digitization and smart automation within their wax pattern production facility. Wax pattern production forms part of the company's investment casting operations. A collaborative research project was developed to implement a systematic approach to technology adoption.

Following initial scoping meetings and company visits, it was agreed that, although functional, the existing wax pattern production facility and procedures were not optimized for greatest operational performance. As such, a discrete event simulation model of the current-state system was developed and analyzed. In preparation for the development of the production model, digital data was recorded and, where this was not available, analogue data was collected and converted for digital input. Although understanding and deployment of lean principles was evident within the wider organization, the wax pattern production facility exhibited clear examples of waste activities which needed to be eliminated prior to the implementation of further digitalization measures.

Once lean principles had been adopted, the development team worked with automation integrators to adapt the process model, simulating a range of potential digitization and smart automation solutions. The simulation allowed a series of "what if" production scenarios to be evaluated. The simulations also allowed the impact various levels of investment would have on the production system as a whole. This helped to provide a solid business case for investment within the department. A Virtual Reality (VR) interface was used to engage production operators in the development process to evaluate how they would interact with proposed interventions and to obtain feedback and insights, from an operational standpoint. It was noted that during both the incorporation of lean principles and the integration of digital and automation technologies, the modelling and simulation work permitted a series of process improvement iterations to be evaluated and optimized prior to physical implementation.

3.3 Case study 3

Case three is focused on work undertaken by a process and productivity improvement solutions provider based in Bridgend, Wales. Their business model focusses on supporting all areas of manufacturing, quality, and process engineering. This ranges from digital solutions integration to task-based activities and skills development through training. Established in 2005 by founding directors with over 50 years' experience in a broad range of manufacturing sectors, the organization has since developed a strong track record of supporting a wide range of SMEs across South Wales. The company has developed its own cloud-based interactive software solution, which is built upon a customizable and flexible framework, and can be used as a platform from which

increased levels of digital data can be collected, recorded, analyzed and acted upon - with a view to increasing value adding activity and reducing operational waste. Through interviews with the customer-facing and development teams at the case company, it has been possible to identify recurring themes and patterns which typically emerge when SMEs advance towards the digitalization of their operations.

Prior to any digital intervention, it is often found that heuristics such as overall equipment effectiveness (OEE) are already being used to monitor performance. However, the implementation of the measurement, data collection and analysis tools tend to be labor intensive and inefficient. When embarking on a digitalization journey, many organizations are seen to be paralyzed by the size of the challenge and the range of technologies available. Value Stream Mapping (VSM) is frequently used as an evaluation technique. If they have not already been effectively embedded, lean principles need to be considered and implemented. This is especially relevant in medium- to high-volume production scenarios.

When implementing digital solutions, progressive SMEs can be tempted to move directly to autonomous measurement and data collection. However, this approach often bypasses production staff, resulting in little or no buy-in to the overarching goals associated with digitalization and continuous improvement. In terms of organizational culture, there are widespread, tangible benefits to involving production staff in the manual recording and inputting of data prior to introducing more autonomous methods of data collection. This approach encourages production staff to become involved in the transition and to recognize their ownership of both the data and resulting improvements.

Following the integration of automatic, digital production monitoring systems, control measures need to be implemented to ensure the data and analytics are being used to drive authentic productivity improvement interventions rather than merely serving as a manager's "finger pointing" function. Whilst digitalization has aided many manufacturers in realizing new and enhanced opportunities, it is important for SMEs to maintain focus on the greater purpose behind their adoption – the drive to increase value adding activity and to reduce operational waste. To fully realize its potential, digitalization in manufacturing and the insights which it can offer still needs to facilitate actionable improvement interventions or improved decision-making capabilities.

4 Discussion

Drawing on the practical insights from each of the three cases studies, it is clear to see that there is a greater need for SMEs to approach the digital manufacturing frontier first by adopting lean as an alternative business strategy. The level of organizational readiness observed in each of the three case studies also indicated the requirement of a *lean first ... then digitalize* approach. Additionally, we also observed the need to distinguish between digitization and digitalization [16]. Digitization simply refers to taking analog information and encoding it in a digital format so that computers can store, process, and transmit such information. Digitalization, on the other hand, is the process of employing digital technologies and information to transform business operations [17]. We consider

these three phases as the foundations of an SME-friendly approach to Industry 4.0 implementation:

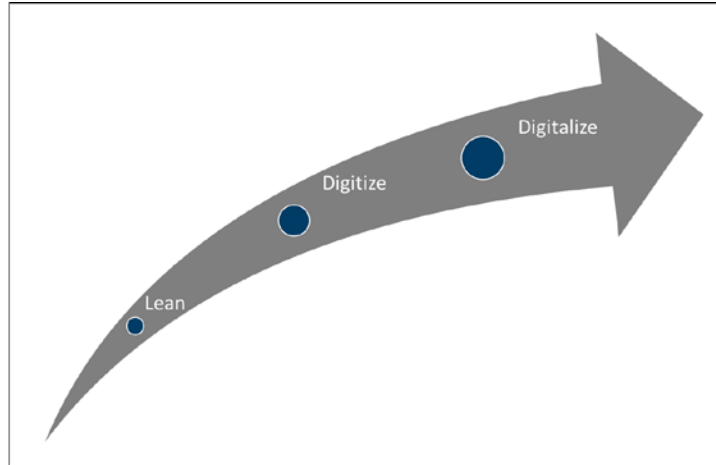


Fig. 1. The *Lean First... Then Digitalize* Approach

We also noticed that each of the lean principles described in [18] provide a suitable point of departure for digitization and digitalization initiatives, examples of which are presented as reference guidelines for Industry 4.0 implementation in SMEs in Table 1.:

Table 1. Reference Guidelines for Industry 4.0 Implementation in SMEs.

Lean (Analogue)	Digitize	Digitalize
Customer Value	CAD-CAM, e-documents, tablets	H & V system integration, (Big) data analytics
Value stream(s)	Basic modelling (e.g., Excel)	Advanced simulation
Create flow	Andon boards (stop, call, wait), Internet of things (IoT)	H & V system integration, Digital shadow / digital twin
Establish pull	Electronic Kanban	Artificial intelligence
Seek perfection	Digital team boards / SFM	Advanced simulation, VR, AR

5 Conclusion

We set out to answer the research question: *How can SMEs implement and benefit from Industry 4.0?* As such, we carried out three exploratory case studies, first to gauge the organizational readiness levels of SMEs embarking on a digital transformation, and then second to develop an SME-friendly approach to the subsequent implementation efforts that ensue. We discovered that the digital transformations of SMEs must often begin far from adopting digital technologies – rather by first adopting lean thinking and

practice as an alternative business strategy. In addition to the low levels of awareness of smart manufacturing, SMEs also lack awareness of what lean manufacturing really entails. As such, we developed a *Lean First ... Then Digitalize* approach to implementing Industry 4.0 in SMEs. This is very much in line with the research of [19], which argues that "*lean is needed as a foundation for successful digitalization*" (p. 82), although the authors also suggest a positive correlation between the lean maturity and digital maturity of firms. A lean first approach was also presented by [20], which suggests lean management be applied first in service operations before such firms turn to automation and IT solutions. Automating (or indeed digitizing) wasteful operations will only lead to *digital waste* [15, 21].

There was no evidence from either of the case studies that suggested "lean improvements" are more effective than "smart improvements" to reach the companies' specific objectives. Rather (as illustrated in Fig. 1.), smart improvements become lean improvements when digital technologies are deployed to enhance fundamental lean practices. We suggest that these two "types" of improvement can be considered progressive, with organizational learning at the core.

Furthermore, we suggest that SMEs should begin with developing an awareness of the core lean principles – *customer value, value stream, flow, pull, and perfection* [18]; before selecting and adopting lean and / or digital tools. As such, the tools themselves should be seen as countermeasures to the real problems which the firms are struggling with, rather than simply implementing them on a nice-to-have basis. Discovering real problems demands a deep understanding of the *gemba* (lean jargon for "the real place", e.g., the shopfloor – where value is created), and as such, digitalization efforts begin there. *Gemba*, as they say, is the greatest teacher [22].

Though it was not a primary aim of the study, we also discovered that this approach also serves as a means of realizing *greener*, more sustainable production – where the resulting elimination of waste has impacts on both the economic, social, and environmental bottom-lines. We therefore conclude that both lean and digitalization have a core role in the sustainability efforts of organizations, including SMEs.

In terms of limitations, we understand that the insight gained from just three case studies cannot be assumed to be representative of all SMEs. However, we do suggest that many SMEs could benefit from adopting a *Lean First ... Then Digitalize* approach to Industry 4.0 implementation. Further work should seek to apply this framework to a wider sample of SMEs, in different industries and in different countries.

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