Enablers and inhibitors of digitalization as part of continuous improvement

Alinda Kokkinou, Ton van Kollenburg, Gijs Mathijssen, Emma Vissers, Sem van Doren

Abstract:

To deal with an increasingly competitive environment, organizations are combining continuous improvement practices with digitalization to accrue their benefits on operational performance and achieve operational excellence. The purpose of this study was to identify the enablers and inhibitors of digitalization as part of continuous improvement projects.

A mixed-methods sequential explanatory research design consisting of an online survey and semi-structured interviews was used to examine how digitalization technologies have been incorporated in continuous improvement projects by organizations.

Key enablers of digitalization were found to be leadership capabilities, strategic direction, stakeholder involvement, system compatibility, data quality, and giving employees room to experiment. Knowledge of digitalization was found to affect all these enablers.

The empirical findings are based on a non-probability sample of Dutch CI practitioners, limiting their generalizability.

The empirical findings highlight the need for organizations to adopt a structured approach to implementing digitalization as part of their CI projects, starting by ensuring that the necessary knowledge and skills are either present or accessible to the organisation.

The empirical findings show that enablers of digitalization in the context of continuous improvement are strongly interlinked, and thus require a holistic approach.

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Introduction

Operational excellence is increasingly a requirement for organizations to remain competitive in a dynamic business environment (Sim and Rogers, 2008). Globalization has led to increased competition from specialist suppliers benefiting from economics of scale, but this has made supply chains longer and thus more vulnerable to disruptions (Holmström *et al.*, 2016). Concurrently, technological developments have led to reduced costs for hardware and software and advances in big data analytics, favouring competitors who were quicker to adopt these technologies. These same technological developments also fuelled customer demand for more customized products (Shahin *et al.*, 2020), requiring organizations to alter their business models. To deal with the aforementioned increases in competitive pressure, external threats, and customer demands, organizations are increasingly combining continuous improvement (CI) practices with digitalization to accrue their benefits on operational performance and achieve operational excellence (Buer, Strandhagen, *et al.*, 2018; Kaswan *et al.*, 2023; Khanchanapong *et al.*, 2014).

CI is a general term that takes attributes from other quality practices and methodologies (Bhuiyan and Baghel, 2005). CI is frequently linked to the Japanese "Kaizen" (Imai, 1986), referring to "*a continuous improvement process involving everyone, from managers and workers alike*" and originating from the Japanese word Kaizen meaning "change for the better." Kaizen is characterized by its incremental process-oriented approach and participation of the workforce in process and product improvement (Carnerud *et al.*, 2018). This process-oriented incremental approach to improvement is operationalized through the Plan-Do-Check-Act (PDCA) cycle aimed at setting a target for the improvement plan, implementing the plan, checking its performance, and standardizing the new process (Singh and Singh, 2015). While some debate exists whether CI and Kaizen are synonymous (Carnerud *et al.*, 2018), the consensus is that they overlap to a great extent, sharing the characteristics of an incremental and cyclical activity meant to improve (Sanchez and Blanco, 2014). Organizations engage in CI practices to improve responsiveness, decrease waste and lead times, and increase flexibility (Buer, Strandhagen, *et al.*, 2018).

More recently, digitalization has also been hailed by organizations as a way to increase their internal efficiency (for example by improving their product development and/or manufacturing processes) and/or add value for customers and other stakeholders (for example through more sophisticated products and services) (Björkdahl, 2020). In the context of manufacturing, digitalization has led to the concept of Industry 4.0 or Smart Industry (Rosin *et al.*, 2020) and is "the current trend of automation technologies in the manufacturing industry" (Shahin *et al.*, 2020, p. 2928). Industry 4.0 is expected to contribute to improved products and services through new product development technologies (e.g. 3D printing), and to increased operational benefits through new manufacturing technologies (e.g. digital automation with sensors) (Dalenogare *et al.*, 2018). Both CI and Industry 4.0 have the potential to improve operational performance (Sanders *et al.*, 2016), however combining them has been found to have a synergistic effect on operational performance, and four dimensions thereof, namely cost, quality, lead time and flexibility performance (Khanchanapong *et al.*, 2014). The integration of Green Lean Six Sigma is also a promising avenue for organizations to improve environmental sustainability (Kaswan *et al.*, 2023)

Previous research has examined how Industry 4.0 can support CI and how CI can support Industry 4.0 (Buer, Strandhagen, *et al.*, 2018), however much remains unclear on how organizations can implement digitalization technologies as part of their CI program (Chiarini and Kumar, 2021). While an extensive body of research has examined best practices of Lean Management and CI implementation (Rijnders and Boer, 2004; Sim and Rogers, 2008), less attention has been given to the implementation of digitalization (Machado *et al.*, 2019) and in particular in the context of CI (Citybabu and Yamini, 2023; Yilmaz *et al.*, 2022). Therefore, the purpose of this study was to examine enablers and inhibitors of implementing digitalization technologies as part of CI projects by first inventorying which digitalization tools are used in the context of CI projects, identifying enablers and inhibitors of using digitalization technologies as part of CI projects, and recognizing patterns in which enablers and inhibitors of digitalization interact in the context CI projects. The main research question for this study is therefore: how can organizations deploy digitalization tools as part of CI projects?

The following section reviews relevant literature about digitalization as part of CI and presents our sub-research questions. Subsequently, the mixed-methods approach employed to address these research questions are detailed. The quantitative and qualitative findings are presented, followed by their discussion and implications for practitioners.

Review of the Literature

Continuous Improvement

CI is the overarching concept used to refer to organizations' efforts towards improving the quality of their products, services, and processes and thus operational performance (Bhuiyan and Baghel, 2005). A comprehensive definition of CI is that of "a never-ending, systematic, and cyclic approach that is happening all the time, striving for perfection by adding more value and eliminating waste, where everyone is involved in improving products, services or processes in all the systems of an organization, thus coming to sustained improvements regarding effectiveness and efficiency, e.g., quality, speed, flexibility, cost, and sustainability" (van Kollenburg and Kokkinou, 2021, p. 261). CI can be seen as a collection of tools and practices, but also as a philosophy. CI includes technical and analytical tools that organizations implement to improve processes, such as the EFQM model and 5S (Rijnders and Boer, 2004). These tools, referred to as hard practices, can be supplemented by soft practices such as small team problem solving and supplier partnerships (Bortolotti *et al.*, 2015).

CI's origins have several attributions, the earliest being the Second Industrial Revolution, when employees were encouraged to actively participate in product and/or process improvement as part of scientific management (Singh and Singh, 2015). More common and recent attributions have

been to statistical process control (Shewhart, 1931) and to the Japanese "Kaizen" (Imai, 1986). While initially, applications of CI that were documented involved tools and process innovations (Li *et al.*, 2016), CI evolved to include more comprehensive methodologies such as Total Quality Management, Lean, Six Sigma, and Lean Six Sigma (LSS). From this perspective, CI methodologies are focused on bringing "unceasing improvement in the organizational processes" and increase their operational performance (Sunder and Mahalingam, 2018, p. 4894). Despite their commonalities, these CI methodologies have distinct origins and underlying principles. Lean has evolved into a complex and philosophical methodology (Åhlström *et al.*, 2021; Hines *et al.*, 2004), focused on eliminating waste and non-value-added activities. It is viewed as having merged from the Japanese Toyota Production System (TPS) in the 1950s. Lean includes tools such line balancing, the 5S method, Single Minute Exchange of Dies (SMED), Value Stream Mapping (VSM) and visual management (Drohomeretski *et al.*, 2014; Koning *et al.*, 2008). Six Sigma is a methodology emphasizing the use of statistical methods to reduce defects and variations in products and services (Linderman *et al.*, 2003). It was introduced in 1986 by Motorola, and gained famed through the publicized benefits achieved by GE in the late 1990s (Henderson and Evans, 2000). Lean and Six Sigma were found to synergize well, leading to the development of LSS, a hybrid methodology encompassing Six Sigma's organizational structure and stepwise methodology, and both methods' tools and techniques (Koning *et al.*, 2008; Sunder M. *et al.*, 2018). Unlike Lean, Six Sigma, and LSS, TQM relies less on technical tools and more on soft tools (Calvo-Mora *et al.*, 2013; Yusof and Aspinwall, 2000).

Increasingly, organizations are combining methodologies and/or tools (Netland, 2013) to benefit from the synergies they bring in tackling complex problems, and to develop a program that fits their organization, clouding the distinction between Lean, Six Sigma, and LSS (Kokkinou *et al.*, 2022). Similarly, CI practices and digitalization are increasingly combined to benefit from their synergistic effects on cost, quality, lead time and flexibility improvements (Buer, Strandhagen, *et al.*, 2018; Khanchanapong *et al.*, 2014).

Digitalization and Industry 4.0

The concept of digitalization is similarly an overarching concept, frequently used to refer to the trend of society transforming from analog to digital, encompassing changes in consumer behavior, communication, and information sharing. It also includes the changes in how businesses interact with their environment and generate value (Vial, 2019). Digitalization is frequently confounded with digitization and digital transformation (Gong and Ribiere, 2021; Vial, 2019). Of the three concepts, digital transformation has received the most extensive attention (Reis *et al.*, 2020). Vial (2019) reviewed 23 definitions of "digital transformation" and found they lacked conceptual clarity, often conflating the concept and its impacts. The same criticism can be applied to the concept of digitalization. We therefore adopt Machado *et al.'s* (2019) and Buer *et al.'s* (2018) distinction between digitization, digitalization, and digital transformation.

Digitization, digitalization, and digital transformation can be seen as consecutive steps that are required to transition from analog to fully digital. Machado *et al.* (2019) adopts Legner et al.'s (2017, p. 301) definition of digitization, namely "*the technical process of converting analog signals into a digital form, and ultimately into binary digits.*" This can be achieved through a variety of technologies such as Radio Frequency Identification Tags (RFID), Optical Character Recognition (OCR), and Internet of Things (IoT) connected sensors. Digitization may not be as relevant for born digital organizations, but can be a first hurdle for older organizations that pre-date the digital economy (Sebastian *et al.*, 2020). Digitalization is defined as "*the use of digital data and technology to automate data handling and optimize processes*" (Buer, Fragapane, *et al.*, 2018, p. 1036). Digitalization benefits organizations by enabling them to improve their internal efficiency (e.g. by making manufacturing processes more efficient and/or making product development processes more effective) and to add value for their customers and other stakeholders (e.g. by ameliorating products and services) (Björkdahl, 2020). Digitalization is distinct from digital transformation, which is broader concept that includes *changes in the*

business models, activities, processes, and competences to enable to have all benefits of the full deployment of the new technologies" (Machado *et al.*, 2019, p. 1114). From this perspective, digitalization is a better with CI fit than digital transformation, as it is scoped around operational performance.

Part of the inconsistent definition of digitalization is due to the diversity of disciplines in which it has been examined. In supply chain, business and information systems research, digitalization is typically viewed through the lens of big data, with extensive attention devoted to concepts such as Big Data Analytics (BDA), and Big Data Analytic Capability (BDAC) (Fosso Wamba *et al.*, 2018; Mikalef *et al.*, 2018). Studies in this line of research are typically anchored in two well-recognized theories, the Resource Based View (RBV) and the Dynamic Capability View (DCV) (Teece *et al.*, 1997; van de Wetering *et al.*, 2019). In manufacturing research, digitalization is viewed through the lenses of Industry 4.0 and Smart Manufacturing. This line of research has focused on the application of specific technologies associated with digitalization such as IoT, robotics and automation (Rosin *et al.*, 2020; Shahin *et al.*, 2020).

Unlike research on BDA and BDAC, research on Industry 4.0 and Smart Manufacturing, also in combination with CI, has been fragmented and discipline-specific (Ivanov *et al.*, 2021), and has not adopted a consistent theoretical framework. This is a common criticism within the operations management literature as its focus is considered to be more problem-driven than theory-driven, motivated to improve managerial decision-making instead of developing theory (Schroeder, 2008; Slack *et al.*, 2004). A recent exception is Pérez-Rave *et al*. (2023) who applied DCV to CI projects and conceptualized the hard and soft dimensions of CI projects to identify five dynamic capabilities: CI ideation, absorption, integration, coordination and synergy. These dynamic capabilities helped explain why certain CI projects succeeded and others failed and can be applied to CI projects that include digitalization tools.

Continuous Improvement and Digitalization

The synergistic effect on operational performance of combining Industry 4.0 and CI methodologies such as Lean and Six Sigma has been widely recognized (Buer, Strandhagen, *et al.*, 2018; Ojha, 2023; Pongboonchai-Empl *et al.*, 2023; Sanders *et al.*, 2016). Benefits of combining them include reduced waste, reduced costs, improved leveling of production (Powell *et al.*, 2018), and increased system flexibility and quality performance, (Tortorella *et al.*, 2021). Until recently, the mechanisms by which CI and Industry 4.0 synergized remained unclear, with some researchers hypothesizing that Industry 4.0 enabled Lean manufacturing (Rosin *et al.*, 2020), others hypothesizing that Lean manufacturing enabled Industry 4.0 (Pozzi *et al.*, 2023), and yet a third stream hypothesizing an interaction effect (Buer, Strandhagen, *et al.*, 2018). More recently, empirically-based research studies have found support for the hypothesis that Lean management enables Industry 4.0 (Buer *et al.*, 2021; Pozzi *et al.*, 2023; Rossini *et al.*, 2022, 2023; Tortorella *et al.*, 2021).

Digitalization technologies, also referred to as Industry 4.0 technologies, are diverse, including tools that can be used to interface the digital and physical world such as sensors and augmented/ virtual reality; data related tools such as big data and BDA, artificial intelligence, blockchain; and robots, including automated guided vehicles (Ivanov *et al.*, 2021). In an extensive review of the literature, Vinod *et al.*, (2020) examined the application of Industry 4.0 technologies through the lens of the different CI methodologies. Their approach of distinguishing between CI methodologies will be followed below.

Lean and digitalization tools and technologies were found to be interconnected, with Lean supporting the application of Industry 4.0 (Buer, Strandhagen, *et al.*, 2018; Saxby *et al.*, 2020; Vinodh *et al.*, 2020). Their combination has led to the concept of Lean 4.0, which refers to a technologically supported Lean production systems (Javaid *et al.*, 2022) and the related term Lean Automation (Kumar *et al.*, 2021; Rossini *et al.*, 2022; Tortorella *et al.*, 2021). By integrating

digitalization tools and Lean principles, organizations can achieve several outcomes. By investing in data, BDA tools, and AI, organizations can move towards real-time data-driven decision-making (Chiarini, 2020), thereby increasing their responsiveness to changes in their environment (Citybabu and Yamini, 2023; Ojha, 2023). Organizations can also use robots and COllaborative roBOTs (COBOTs) to automate their processes (Citybabu and Yamini, 2023; Kaswan *et al.*, 2023; Ojha, 2023), increase the modularity of their production system and the flexibility of their equipment (Ojha, 2023). Industry 4.0 thereby also support the principle of continuous flow (Rosin *et al.*, 2020). The use of Artificial Intelligence (AI) can increase the quality of products, and accuracy of forecasts, and more generally, the effectiveness of process improvement activities (Kumar *et al.*, 2021; Ojha, 2023). Organizations can also further empower their employees through improved training possibilities offered by technologies such as Augmented Reality and Virtual Reality (VR) (Javaid *et al.*, 2022; Rosin *et al.*, 2020; Tortorella and Fettermann, 2018).

Through their emphasis on statistical methods to reduce defects and variations (Linderman *et al.*, 2003), Six Sigma and LSS rely heavily on data and data analytics (Kaswan *et al.*, 2023; Vinodh *et al.*, 2020). Consequently, digitalization tools have extensive application in LSS projects (Antony *et al.*, 2023; Chiarini and Kumar, 2021). For example, IoT technologies such as sensors can be used to collect vast amounts of process and product information in real time. BDA tools can then be used to analyze these vast amounts of information effectively and timely (Antony *et al.*, 2023). Connectivity technologies such as cloud systems can be used to allow process and product monitoring by off-site experts. The same approaches can be used for process improvement through a Smart DMAIC approach, or as part of a more data-driven approach to the Voice of the Customer (VoC) (Citybabu and Yamini, 2023). Antony *et al.* (2023) identified several benefits of integrating LSS and Industry 4.0, including improved cost competitiveness, increased flexibility, and reduced waste.

The above review shows that digitalization encompasses a wide range of tools and technologies, with commensurate applications in the context of CI projects. Nevertheless, the majority of studies reviewed consisted of literature reviews (Antony *et al.*, 2023; Chiarini, 2020; Citybabu and Yamini, 2023; Javaid *et al.*, 2022; Macias-Aguayo *et al.*, 2022; Pongboonchai-Empl *et al.*, 2023; Vinodh *et al.*, 2020). This leads to our first sub-research question: *what digitalization tools are used by organizations in the context of continuous improvement? (sRQ1)*

Enablers and Inhibitors of Digitalization as Part of Continuous Improvement

Organization implement CI initiatives for diverse reasons, including internal objectives (e.g. cost reduction, key performance indicator improvement) and external reasons (e.g. pressure from customers and/or suppliers) (Kumar *et al.*, 2011). Extensive attention has been given to the enablers and inhibitors of CI, also frequently referred to as "readiness factors" or Critical Success Factors (CSFs) (Antony, 2004, 2014). The consensus in this line of research is that the ability of the organization to link the objective of the CI initiative to its business strategy through the selection of projects and metrics is decisive for its success (Bamford *et al.*, 2015; Beard and Butler, 2000). Other important enablers of CI include commitment and support from leadership, employee involvement, having a customer orientation, and training as a mechanism for knowledge transfer (Desai *et al.*, 2012; Garcia-Sabater *et al.*, 2012; Kokkinou *et al.*, 2021; Laureani and Antony, 2012; Manville *et al.*, 2012; Timans *et al.*, 2012).

Key enablers and inhibitors of the integration of CI and digitalization that have been identified through literature review can be categorized in tangible, intangible, or technology (Gupta and George, 2016), or in the relatively similar people, process and technology aspects (Citybabu and Yamini, 2023). Applying the latter classification, people aspects include leadership, and specifically top management support and commitment and long term vision; organizational culture, for example stimulating the involvement of employees and stakeholders; and competency development, for example through investment in staff training (Citybabu and Yamini, 2023; Kaswan *et al.*, 2023; Macias-Aguayo *et al.*, 2022; Ojha, 2023; Vigneshvaran and Vinodh, 2021;

Yilmaz *et al.*, 2022). Process aspects encompass integration, management systems, and compliance (Citybabu and Yamini, 2023). Technology aspects include data, data analytics, and connectivity and scalability, requiring investments in IT infrastructure and interoperability of IT systems (Citybabu and Yamini, 2023; Macias-Aguayo *et al.*, 2022).

A comparison of the key enablers of the integration of CI and digitalization shows that it mostly mirrors the enablers of CI. The role of knowledge and skills appears more important when digitalization is involved. This is supported by Kurpjuweit *et al*. (2019) who identified the use of pilot studies, external expertise, visiting other organizations, and knowledge exchange as important activities in a study of the implementation of visual management. Another key difference is the role of IT, which is an enabler of digitalization, but not CI. Organizations that have already implemented aspects of CI will already have several key enablers in place (Antony *et al.*, 2023) as CI has been recognized as a success factor of Industry 4.0 (Pozzi *et al.*, 2023). This leads to the second sub-research question: *what are enablers and inhibitors of using digitalization technologies as part of CI projects? (sRQ2)*

Enablers and inhibitors of digitalization do not operate in isolation of each other, instead they interact to reinforce each other. For example, previous research has found that, in the context of organizations developing their data analytic capability, a lack of knowledge about digitalization impeded managements' ability to make decisions about IT infrastructure (Kokkinou, Kollenburg, Mandemakers, *et al.*, 2023). Therefore we ask: *what are patterns in which enablers and inhibitors of digitalization interact in the context CI projects? (sRQ3)*

Design/ methodology/ approach

The present study employed a mixed-methods sequential explanatory research design (Ivankova *et al.*, 2006) consisting of an online survey followed by semi-structured interviews. The purpose of the online survey was to examine which digitalization tools had been implemented successfully in CI projects and which enablers and inhibitors contributed or hindered their use. The purpose of the semi-structured interviews was to gain a more in-depth understanding of the patterns in which these enablers and inhibitors interacted. For both online survey and semi-structured interviews the unit of analysis was the CI project (Pérez-Rave *et al.*, 2023) in which digitalization tools were involved.

Survey

Participants to the survey were recruited from a database of 1,650 CI practitioners in the Netherlands by e-mail. The online survey administered through Qualtrics consisted of closed and open questions. The closed questions inquired about the nature of CI initiative and the digitalization tools employed. While no single list of digitalization technologies exist, we based ours on Rossi *et al.*'s (2022) and Macias-Aguayo *et al*'s (2022) reviews and included a range of digitalization tools and technologies that enable information flows (big data, AI, blockchain, online teamworking), physical flows (robots / Automated Guided Vehicles -AGVs) and that span the physical/online (IoT, cyber-physical systems, 3D printing, augmented reality, digital twins). Unlike previous research on similar topics (Ivanov *et al.*, 2021), we chose to use open questions to inquire about the purpose, enablers, and problems of employing digitalization as part of CI in order to elicit participants' spontaneous thoughts. The open questions were coded using inductive coding procedures (Braun and Clarke, 2006) and used to develop an interview guide that was subsequently used for semi-structured interviews.

Semi-Structured Interviews

Semi-structured interviews were conducted with key informants from six organizations currently introducing digital tools in their CI projects (shown in Table 1), following the procedures of Ralston and Blackhurst (2020). Organizations were recruited from the network of organizations involved in the Minor Continuous Improvement of the university where the researchers are employed. Approximately 25 organizations actively participate in this minor, by hosting teams of

students to execute CI projects. Key informants were defined as individuals who were actively involved in the coordination and execution of CI projects. To ensure reliability, semi-structured interviews were conducted according to a pre-defined list of questions and focused on recent CI projects participants had been involved in. The complete interview guide and interview protocol were pre-tested in cooperation with professionals of equivalent experience to the intended participants, contributing to construct validity. To promote internal validity, an extensive review of the literature was conducted to establish that this line of research was relatively undeveloped, and a qualitative approach thus justified. Finally, in the interest of external validity, we used purposive sampling to sample organizations who were actively engaged in implementing digitalization tools as part of CI projects but placed no restrictions to the nature of CI implementation and type of digitalization tool used.

All interviews were conducted in participants' native language (Dutch). With participants' permission, interviews were recorded, freeing up the researchers to observe and take notes (Braunscheidel *et al.*, 2011; Ralston and Blackhurst, 2020) All interviews were transcribed and subsequently coded in Atlas.ti by applying the steps of thematic analysis as described by Braun and Clark (2006), namely (1) familiarization with the data, (2) inductive coding, (3) identification of theme, (4) refining of themes, (5) selection of illustrative quotes. The findings were discussed with the same panel of professionals who pre-tested the interview protocol.

[Insert Table 1 approximately here]

Findings

Quantitative Findings

Following the initial mailing, 131 responses were obtained. The response rate of 7.94% is consistent with previous online studies (REF). Of the responses obtained, 100 were complete and thus usable. The analysis of demographic variables showed that most respondents were from production industries (34%), followed by professional services (30%). A minority were from the healthcare industry (4%) and construction industry (3%). Most respondents indicated being involved in the CI project as project leader (32%), management (26%), or consultants (25%). Regarding the nature of the CI initiative, 44% of respondents indicated having implemented Lean, Six Sigma, or LSS, 18% using agile, while 17% reported having implemented Total Productive Maintenance (TPM). Over half of the organizations (55%) also indicated using some form of project-based working.

[Insert Figure 1 approximately here]

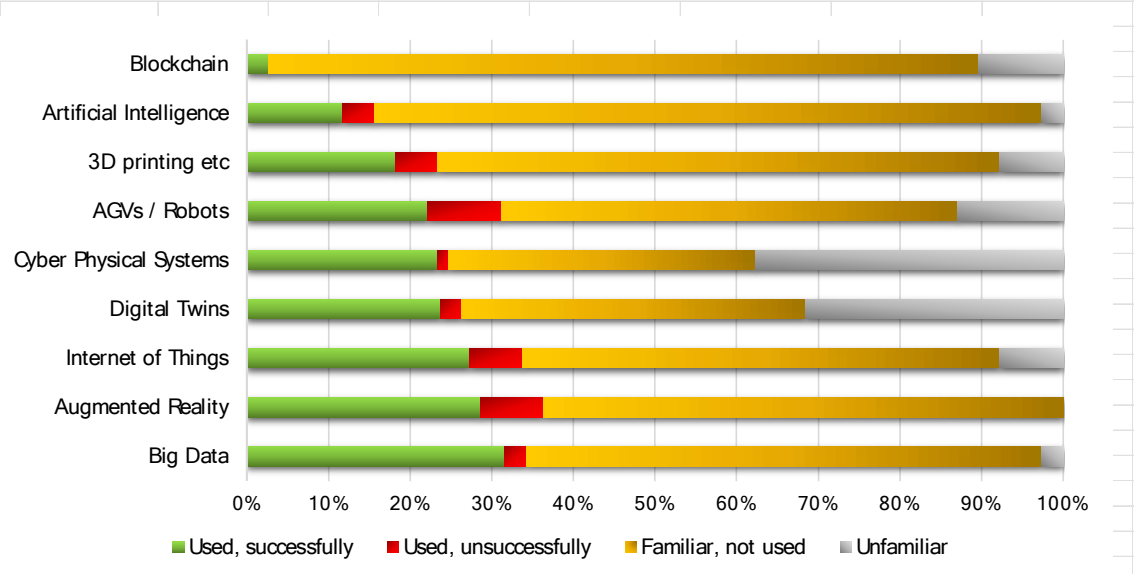


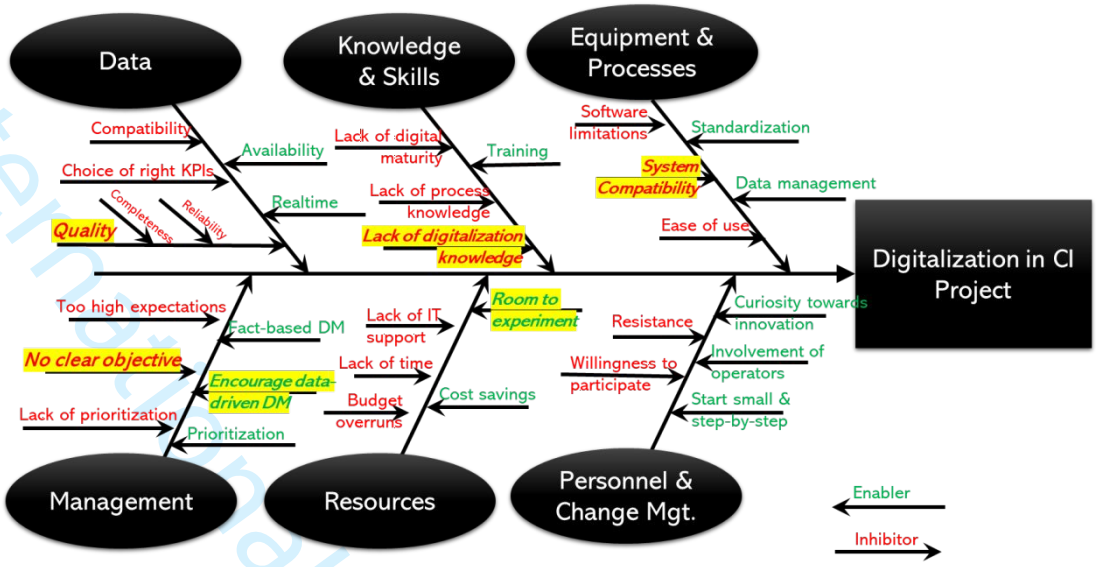
Figure 1 – Digitalization Tools for CI Improvement

The most used digitalization technology for CI projects in our sample were Big Data, Augmented Reality and IoT (see Figure 1). Using a chi-square test, we found a marginally significant association between industry and use of robots/AGVs ($X^2(8, N = 74) = 13.510$, $p = .1$) with production organizations reporting using them at higher rates than organizations in other industries. We also found significant relationships between the nature of the CI initiative and the use of digitalization tools. Specifically, we found positive relationships between organizations having implemented Lean, Six Sigma, or LSS and the use of big data/ advanced analytics ($X^2(8, N = 74) = 15.000$, $p < .05$), the use of robots/AGVs ($X^2(8, N = 74) = 25.452$, $p = .<.001$) and the use of augmented reality ($X^2(8, N = 74) = 9.926$, $p = .05$). Organizations having implemented Lean, Six Sigma, or LSS also reported significantly higher familiarity with AI ($X^2(8, N = 74) = 28.591$, $p < .001$).

Qualitative Findings

The analysis of the open questions and interviews using thematic analysis resulted in the identification of enablers and inhibitors of digitalization in the context of CI projects (sRQ2) and patterns therein (sRQ3). The complete set of enablers and inhibitors is shown in Figure 2 and the relations between key enablers and inhibitors are shown in Figure 3.

[Insert Figure 2 approximately here]



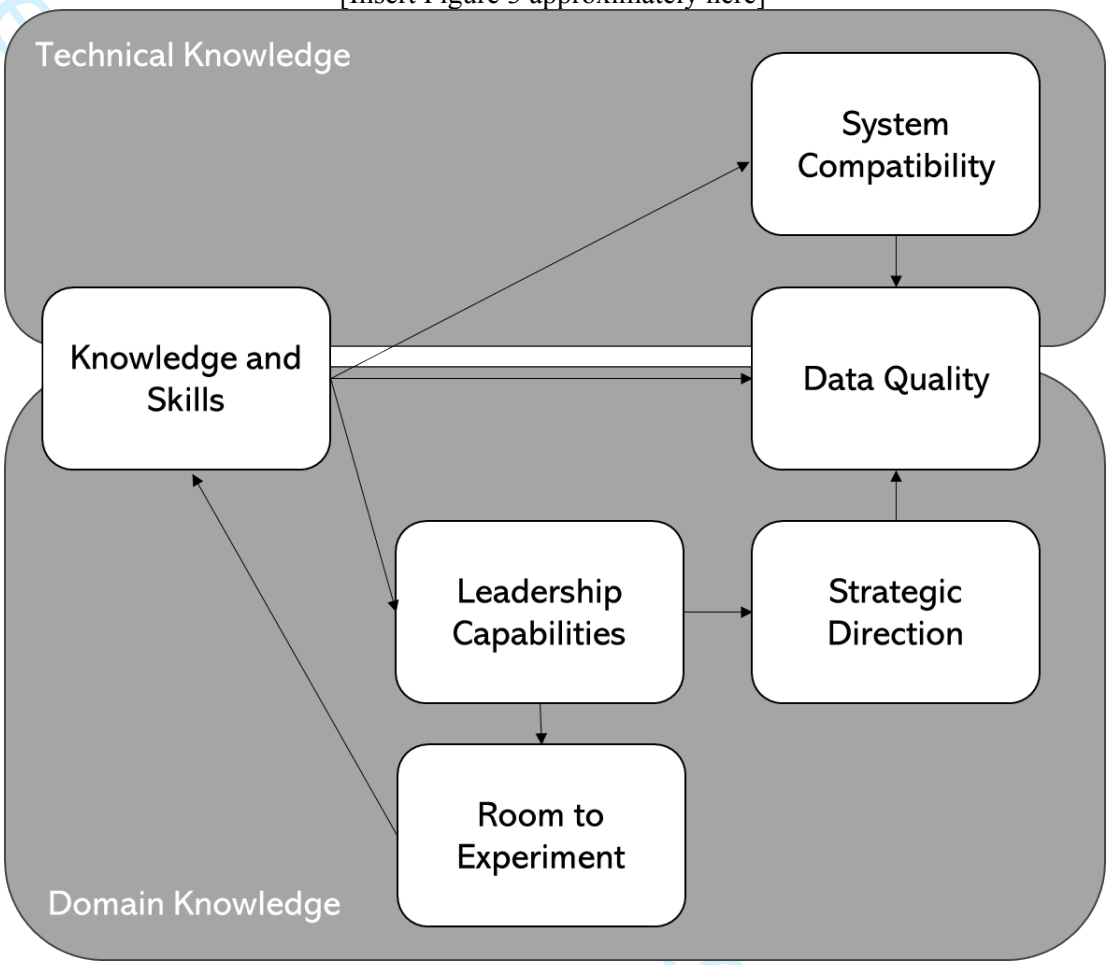
The most important inhibitor of digitalization was found to be a *lack of knowledge* of digitalization and its possibilities. This was mentioned by 21.27% of the survey respondents and all the interview participants. Knowledge of digitalization was deemed important at several stages of the implementation of digitalization tools as part of CI projects, including selection, adoption, and continued usage. Survey participant and interviewees described situations where managers or other decision-makers had to make implementation decisions such as which digitalization technology to invest in without sufficient knowledge to assess its added value to the organization.

The *lack of a clear objective* for digitalization was also reported as an important inhibitor by survey respondents (10.3%) and interview participants (n=3) and was related to the lack of knowledge. Interview participants explained that the lack of knowledge led to management not being able to formulate clear objectives for the implementation of digitalization tools. The management from organization E was described as enthusiastically promoting digitalization top-down, yet no formal digitalization program having been set in motion. The interviewee from organization C described senior management similarly motivated for the company to embrace digitalization. Unlike organization E, organization C had made digital transformation a core element of their strategy, naming it as one of their seven strategic themes, and investing in several digitalization projects. Nevertheless, organizations' stated objective of "adopting industry 4.0" was perceived as too vague, leading to a fragmentation of projects.

This lack of knowledge and skills related to digitalization gave rise to several more inhibitors. Specifically, a lack of knowledge to bridge the business side to the IT side was felt. In organizations with little knowledge of digitalization business analytics and IT were confounded. The interviewee from organization E described an overworked IT department, focused on the technical infrastructure, with little affinity with the business. This led to another important inhibitor, namely *poor data* reported by 19.1% of the survey respondents and five of the interview participants. Issues related to data included the availability of relevant data and a lack of quality of the available data, specifically completeness and reliability. Participants reported that employees on the business side did not have sufficient knowledge to describe the kind of data that they needed. Conversely, IT did not have enough knowledge about the business side to pro-actively ensure that the data needed was of sufficient quality. The interviewee from organization D described the desired situation where *"you need someone that can look over the fence, can connect the IT to the business side. Someone that doesn't only know what the systems can do but also can think along and understands what needs to happen."* The lack of knowledge and skills combined with a lack of clear objective led to difficulties selecting appropriate KPIs. This in turn also impeded the organizations' ability to obtain and use data of sufficient quality. Survey

participants and interviewees also described mistakes being made during implementation and usage due to a lack of knowledge. For example, a survey respondent reported that "*one does not know enough to understand what kind of data is needed and sets the system up incorrectly*."

[Insert Figure 3 approximately here]



System compatibility was mentioned as an inhibitor by survey respondents (17.1%) and interview participants leading to two distinct but related problems. First, systems were implemented in the context of CI projects from within operational silos, oftentimes in parallel to systems deployed for operational purposes from within other operational silos. Even within a silo, many systems were adopted for a specific purpose and a lack of interfacing with other systems was recognized. Conversely, the lack of system compatibility in combination with the operational silos hindered the deployment of existing systems and other digitalization tools in new CI projects. Organization C, in the words of the interviewee: "*has automation here and there, and there is software, and a solution here and an application there. But they are not linked to each other, they are not smart.*" The interviewee from organization B gave an example of implementing a soldering robot to improve throughput time. However, incompatibility of systems, and a lack of knowledge in the organization on how to interface the robot with existing systems, limited the ability to use the robot flexibly and relegating it to highly repetitive tasks to reduce changeover time.

Lack of knowledge was partially offset by employees being curious about the possibilities of digitalization and management creating *room to experiment* with digitalization technologies. Another important enabler of digitalization was management encouraging *data-driven decision-making*, even when not fully knowledgeable of digitalization themselves. Interview participants explained that when management modeled support of data-driven decision-making it created legitimacy for the employees involved. The interviewee from organization F summarized it as

follows: "*As a manager, you need to explain why, give it your attention and stay persistent. You need to let go, but also stay involved*". He proceeded by explaining the importance of creating room to experiment and learn from mistakes: "*mistakes were made, but who made the mistake? That is not relevant. What is more important is that someone can explain what happened and what we learned from it.*"

Finally, all organizations interviewed supported the importance of digitalization tools being *introduced step-by-step with involvement of stakeholders,* and especially employees, to overcome resistance. The interviewee from organization E described the introduction of a Power BI dashboard to monitor on time delivery. Prior to the adoption of Power BI this KPI was reviewed once per year, with limited possibilities to take timely action. The objective of adopting and implementing a Power BI dashboard to monitor on time delivery was to enable stakeholders to take timely actions. The interviewee described a three-month development process starting as a project spearhead by a development team. Subsequently, stakeholders from production were involved to pilot test deliverables. The solution was rolled out to the rest of the organization once it was deemed 80-90% satisfactory. Conversely, the interviewee from organization C described a project where *"the human side was not really considered. A system was thrown at employees. So in the end it wasn't supported by the organization and the project failed."*

Discussion

Using a mixed-methods sequential explanatory research design we examined how digitalization technologies have been incorporated in CI projects by organizations. Across industries, we found the most used technologies in the context of CI projects to be Big Data, Augmented Reality and IoT (sRQ1). However, we found differences across industries in terms of familiarity and adoption of these digitalization technologies, with production industries showing a greater adoption of robots and AGVs. While digitalization and its tools are frequently treated as a single construct, our empirical findings show that their applicability and use differ across industries, illustrating a source of tension between theoretical research and its practical relevance (Slack *et al.*, 2004). This suggests that the digitalization construct is too broad, and that it should be further specified. Ivanov's (2021) distinction between tools interfacing between the digital and physical world, data related tools, and robots is a fruitful start.

Consistent with previous research, we also found that organizations that had implemented CI methodologies such as Lean, Six Sigma, and LSS were more likely to have implemented digitalization tools (Tortorella *et al.*, 2021) and in particular Big Data, Robots/AGVs and Augmented Reality (Rosin *et al.*, 2020; Shahin *et al.*, 2020). For organizations having already adopted the measurement aspects of Lean, Six Sigma, and LSS, implementing digitalization tools is a next step in increasing the volume and variety of data that they can use in their improvement projects (Kaswan *et al.*, 2023) and making their process improvement cycle more data-driven (Buer, Fragapane, *et al.*, 2018; Chiarini, 2020). Similarly, organizations that have identified processes and activities that are repeatable through process improvement activities, can automate them using Industry 4.0 technologies such a AGVs and COBOTs (Chiarini and Kumar, 2021) This supports Rossini et al.'s (2023) finding that at the strategic level, CI is an enabler of Industry 4.0, but that at the operative level, CI and digitalization tools reinforce each other.

We examined the enablers and inhibitors of digitalization tools in CI projects (sRQ2) and illustrated how they are interrelated (sRQ3) in our proposed framework (Figure 3). We identified known enablers of digitalization, including tangible (data quality, system compatibility), intangible (leadership capabilities, strategic direction), and human (room to experiment) factors (Gupta and George, 2016). Unlike previous research that treats these enablers as relatively independent, our empirical findings showed that they are interlinked and describe in detail their interoperability. Our findings support the important role of management and leadership commitment (Citybabu and Yamini, 2023; Macias-Aguayo *et al.*, 2022; Yilmaz *et al.*, 2022), and

highlight specific ways in which they can be enacted. Specifically, management can demonstrate their commitment and support to digitalization efforts by encouraging data-driven decision-making. Management should also involve employees by giving them room to experiment. This is also consistent with success factors of CI that promote problem-solving teams and employee empowerment (Puvanasvar *et al.*, 2008; Yilmaz *et al.*, 2022).

Our empirical findings also showed that leadership needs to link the digitalization efforts explicitly to strategy as this enables them to make better decisions about investments and define relevant KPIs. Formulating relevant KPIs helps in turn to focus efforts to identify relevant data and ensure its quality. This complements previous research identifying poor data quality as an impediment to the integration of CI and Industry 4.0 (Citybabu and Yamini, 2023), by highlighting a cause thereof. These enablers (management leadership and commitment, link to strategy, data quality) are shown to be interdependent. This is consistent with previous research investigating the development of a broader data analytic capability by organizations (Kokkinou, Kollenburg and Mandemakers, 2023) and mirrors findings about the role of leadership in linking CI efforts to the organization strategy (Kokkinou *et al.*, 2022; Laureani and Antony, 2017, 2019), tactics, and operations.

Implications for theory

To the existing body of knowledge regarding enablers and inhibitors of digitalization technologies we add the magnitude of knowledge about digitalization and its tools. Previous research had identified the need for employee training and reskilling in the context of digitalization (Ivanov *et al.*, 2021) and the implementation of digitalization tools (Kurpjuweit *et al.*, 2019). Our findings extend this to show that also in the context of CI projects, knowledge and skills about digitalization are needed at all levels of the organization and fuel the digitalization efforts of the organization. At the top level of the organization, management needs knowledge about digitalization tools to set clear objectives and make the right choices regarding IT investments (e.g. data quality and system compatibility). This nuances previous research that stipulated that management's lack of long term vision is an impediment to the integration of Lean and Industry 4.0 (Ojha, 2023; Vigneshvaran and Vinodh, 2021). Knowledge of digitalization and its tools is also needed at the tactical and operational levels. Our findings show that employees equipped with the knowledge and skills need to be given room to experiment with the technologies, harnessing their intrinsic motivation.

Our findings support previous research that identified investment in IT infrastructure and interoperability of IT systems as key enablers (Macias-Aguayo et al., 2022), yet we show that these are driven by knowledge about digitalization in the organization. Furthermore, we highlight the inhibiting role of organizational silos between business and IT on the one hand, and between departments using distinct systems on the other hand. Collectively, our findings suggest that it is not sufficient for organizations to adopt digitalization tools as part of CI projects. Instead, these organization need to engage in digitalization at the strategic level much in the same way as they have implemented CI through a top-down company-wide strategic initiative (Kokkinou *et al.*, 2022; Lameijer *et al.*, 2021) that encompasses people, process and technology aspects (Citybabu and Yamini, 2023).

Implications for practice

In their pursuit of digitalization in the context of CI projects, organizations should consider embracing digitalization more broadly, and incorporating it in their strategic CI programs. Concretely, there is a clear need for organizations to first ensure that the necessary knowledge and skills are either present or accessible to the organization. Managers and leaders need knowledge and skills about digitalization and related technologies to link these efforts to the organization's strategic objectives. This will in turn improve the effectiveness of capital investments in the necessary IT infrastructure, contributing to system compatibility and data quality. Based on our findings, we propose a sequence of steps.

First, leadership and management need to familiarize themselves with digitalization tools to better understand how they can be used as part of the organization's CI projects to improve operational performance. Management needs to "walk the talk" and demonstrate their commitment and support to digitalization efforts by encouraging and modeling data-driven decision-making. As a first step in step-by-step involvement of stakeholders, management should invite intrinsically motivated employees to participate in digitalization efforts and give them the necessary resources and room to experiment. New organizational structures need to be introduced, promoting cross-departmental collaborations if those are not yet in place. Finally, IT needs to be integrated in cross-departmental collaboration to ensure that IT infrastructure is aligned with the information and data needs.

Limitations and Future Research

While substantial research has been conducted on the topic of combining CI (and Lean manufacturing in particular) with digitalization (and industry 4.0 in particular), the lack of a solid theoretical framework hinders the further development of this line of research. There is a need for consolidation research as Slack et al. (2004) termed it after observing that operations management and practice tended to diverge. Consolidation research uses observations of the world of practice, to model, explain or categorize the associated topics. Given our empirical findings, we propose that further research should examine how new knowledge acquired in the process of introducing digitalization to the organization becomes part of its fabric. Two related theoretical frameworks can be considered, organizational learning and Knowledge-Based Dynamic Capability. Organizational learning is defined as "*the acquisition and development of new knowledge or insights that can potentially change an organization's behaviour towards its strategic and operational milieus*" (Malik and Blumenfeld, 2012, pg. 74) and is thus concerned with how transferring knowledge can contribute to organizational learning and subsequently be used for organizational change (Kokkinou *et al.*, 2021). Knowledge-Based Dynamic Capability links organizational learning to the Dynamic Capabilities View and defines it as "*the capability to acquire, create, and assemble knowledge to sense, explore, and resolve environmental dynamics*" (Horng *et al.*, 2022, p. 23). In the context of CI implementations, organizations use training in different ways to achieve different organizational objectives related to CI (Kokkinou *et al.*, 2021). Future research should investigate how organizations can acquire knowledge about digitalization in such a way that it is embedded in the organization in a durable way and whether structures put in place for CI implementation purposes could contribute therein.

The advantage of the mixed-methods sequential explanatory research design (Ivankova *et al.*, 2006) is the triangulation opportunities provided by following up the quantitative survey with the qualitative semi-structured interviews. Nevertheless, it is important to note that the empirical findings are based on a non-probability sample of Dutch CI practitioners, limiting the generalizability of the findings. Future research should examine the adoption of digitalization tools in CI projects using a probability sample.

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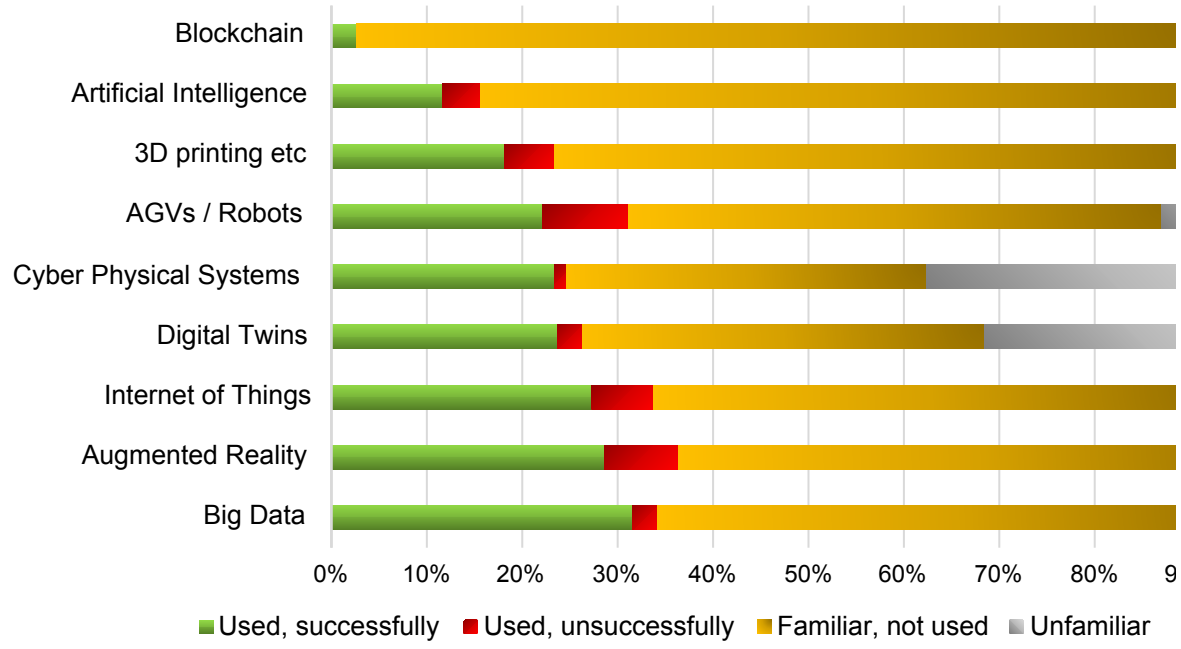
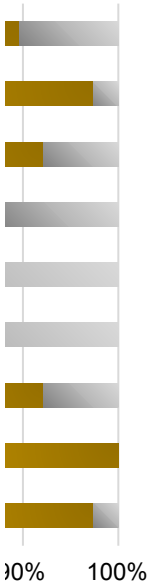
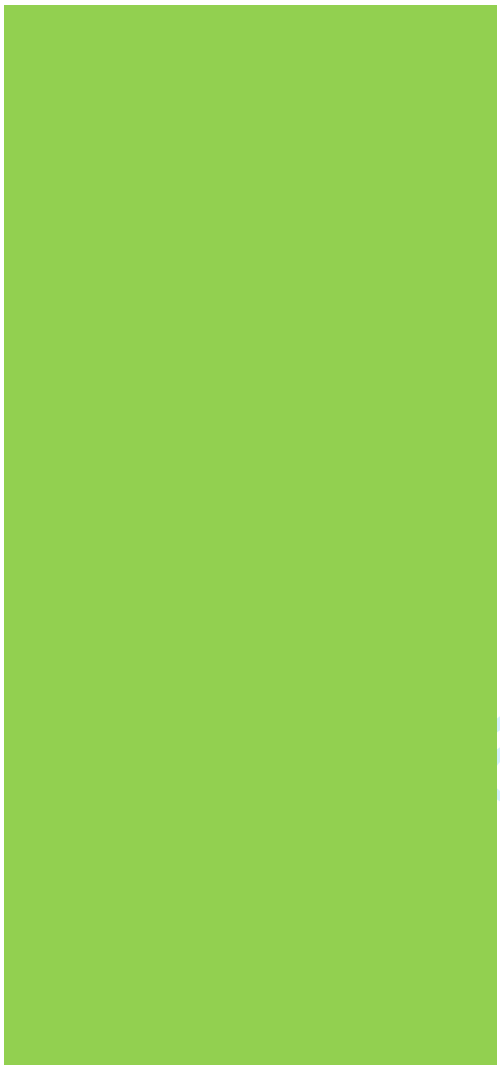
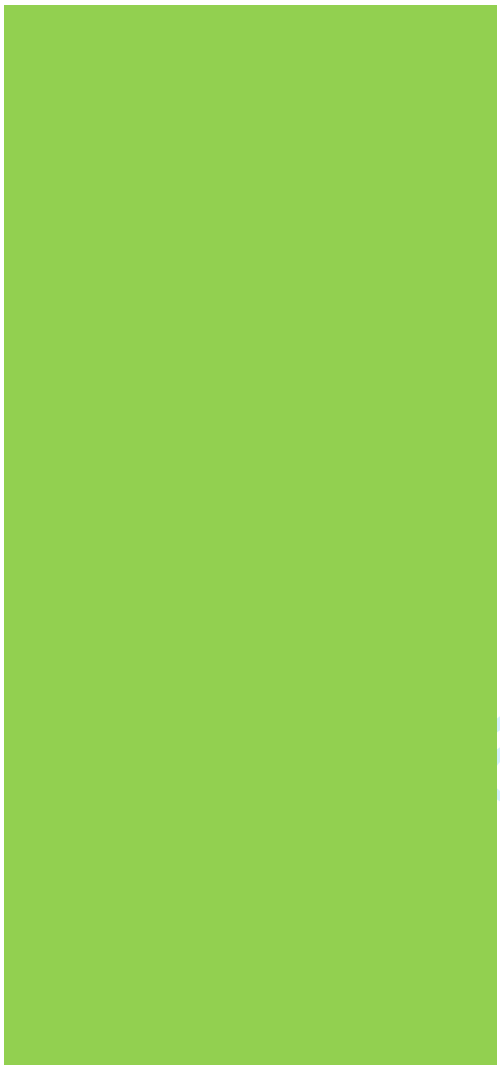
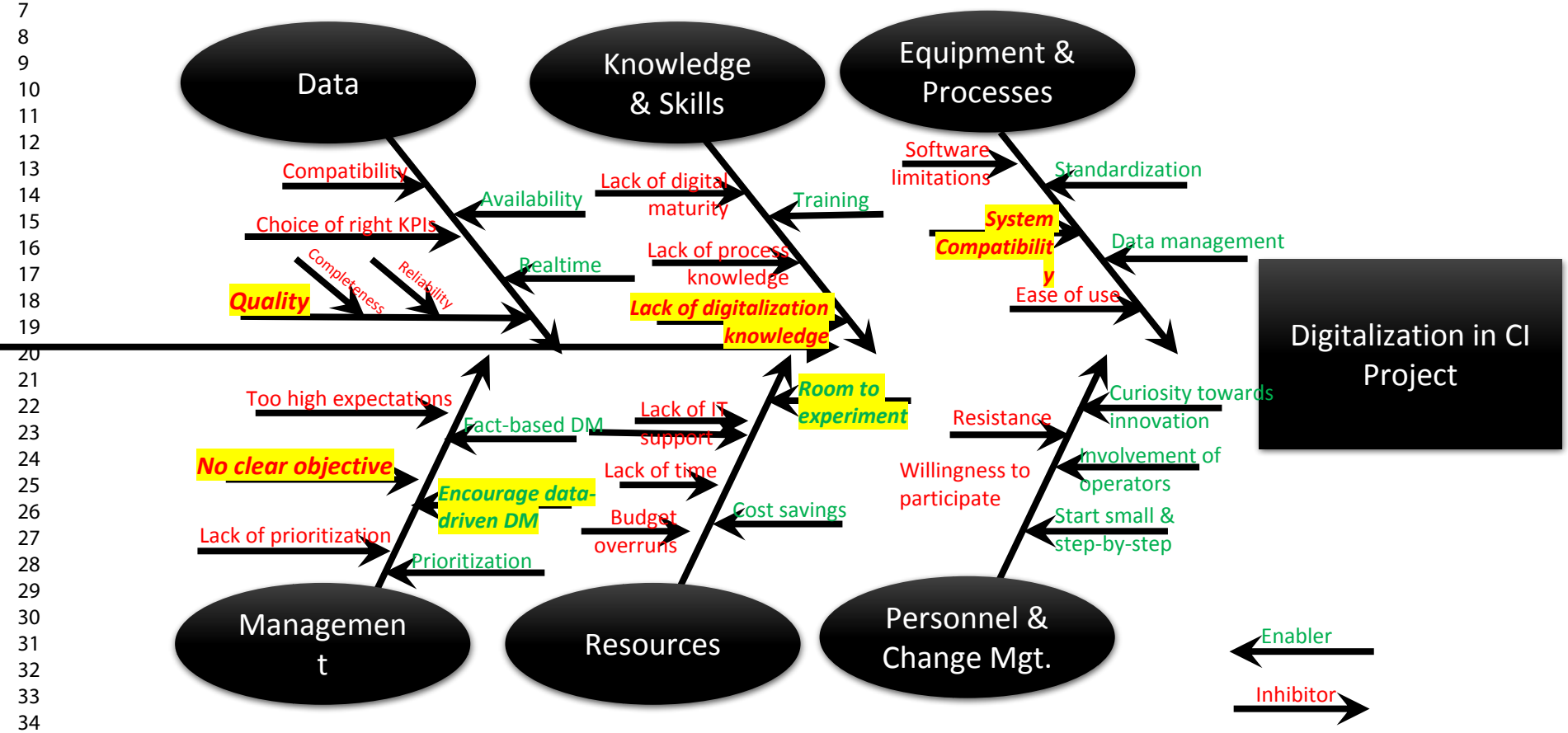


Figure 1 – Digitalization Tools for CI Improvement








Data
Knowledge & Skills
Equipment & Processes
Compatibility
Choice of right KPIs
Quality
Completeness
Reliability
Availability
Realtime
Lack of digital maturity
Lack of process knowledge
Lack of digitalization knowledge
Training
Software limitations
System Compatibility
Ease of use
Standardization
Data management
Digitalization in CI Project
Too high expectations
No clear objective
Lack of prioritization
Fact-based DM
Encourage data-driven DM
Prioritization
Lack of IT support
Lack of time
Budget overruns
Room to experiment
Cost savings
Resistance
Willingness to participate
Curiosity towards innovation
Involvement of operators
Start small & step-by-step
Management
Resources
Personnel & Change Mgt.
Enabler
Inhibitor

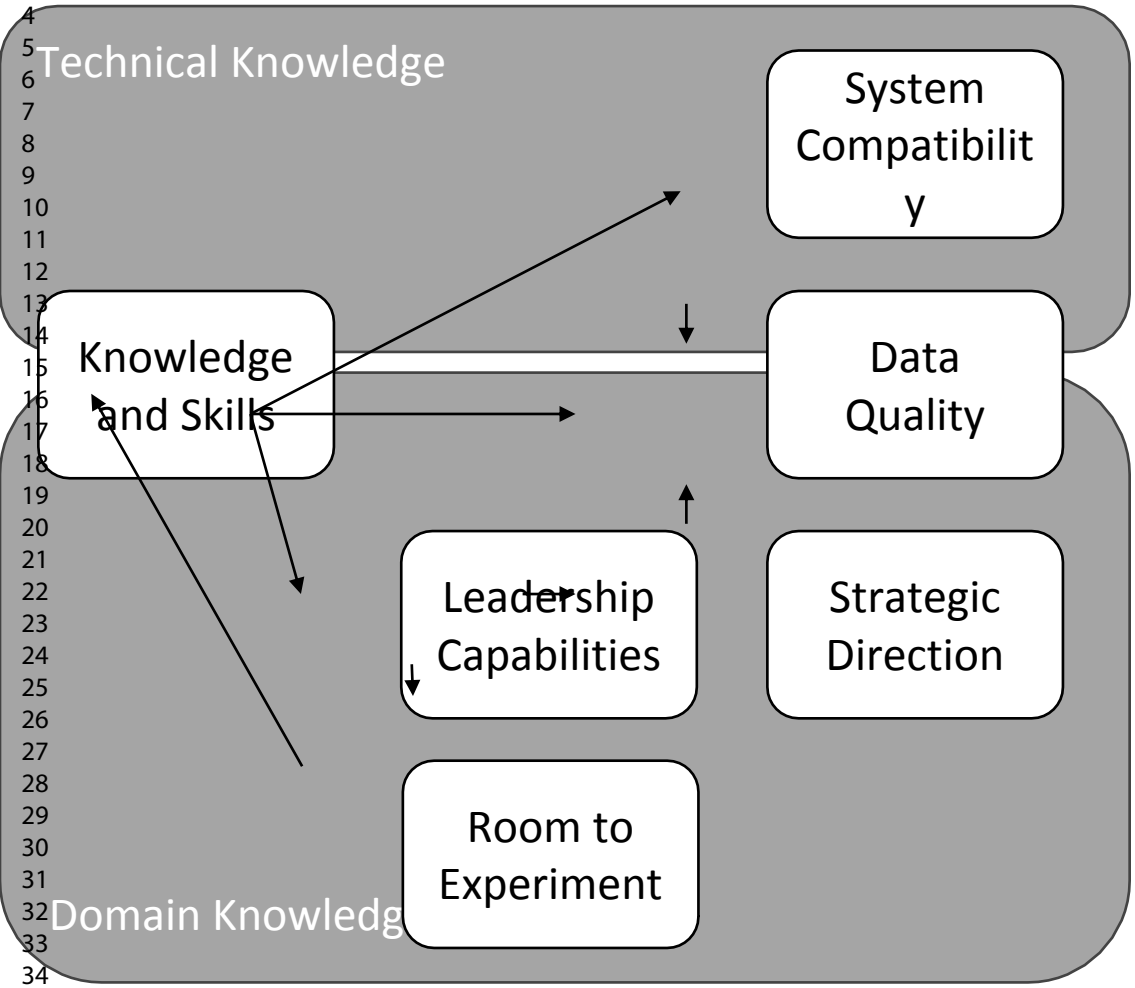

Technical Knowledge
System Compatibility
Knowledge and Skills
Data Quality
Leadership Capabilities
Strategic Direction
Room to Experiment
Domain Knowledg

Table I – Participants in Semi-Structured Interviews

Org.	**Industry**	**CI Initiative**	**Digitalization Tool(s)**	**Participant Role**
A Sm	Production	Lean	Paperless factory	Chief Operating Offer
B Co	Production	Lean	Robot	Continuous Improvement Manager
C As	Production	Op. Excellence	Cloud / App	Operational Excellence Project Mgt.
D Wa	Transportation	Continuous Improvement	Power BI	Chief Operating Officer
E Ch	Production	Continuous Improvement	(A) Dashboards (B) QR-Codes	Continuous Improvement Manager
F Fr	Wholesaler	Lean	Data analytics	Logistics Management

Dear professor Antony, dear reviewers,

Thank you for the constructive feedback and the opportunity to revise the manuscript. We have detailed below how we have responded to each of the reviewers' comments. We have highlighted changes in the manuscript in GREEN.

Referee: 1 / Recommendation: Minor Revision

Comments: Try to answer all the below points.
1) Introduction. Just try to connect CI with Lean kaizen and Deming PDCA (just a short paragraph)

Thank you. We have moved the definition of CI to the literature review and instead prepared a paragraph connecting CI with Lean kaizen and Deming's PDCA.

2) Introduction does not contain your main research question

Thank you. We have expanded the purpose of the study, incorporated the main research question and linked it to what are now the sub-research questions.

3) Continuous improvement it lacks dozens of good papers. First up you should start with a bit of CI history; for instance from Deming to recent authors. We need to know what CI is for Lean, for Six Sigma, and for I4.0. These two papers are fundamental:
- Vinodh, S., Antony, J., Agrawal, R., & Douglas, J. A. (2021). Integration of continuous improvement strategies with Industry 4.0: a systematic review and agenda for further research. The TQM Journal, 33(2), 441-472.
- Chiarini, A. (2020). Industry 4.0, quality management and TQM world. A systematic literature review and a proposed agenda for further research. The TQM Journal, 32(4), 603-616.
- Chiarini, A., & Kumar, M. (2021). Lean Six Sigma and Industry 4.0 integration for Operational Excellence: evidence from Italian manufacturing companies. Production planning & control, 32(13), 1084-1101.

Thank you for this suggestion. We have expanded the literature review and linked CI in more detail to Lean, Six Sigma, and LSS. This also served as a basis to further detail the impact of Industry 4.0 of Lean and Six Sigma/ LSS (see your next comment).

4) CI and Digitalization. Once more you need to quote more recent and relevant papers.

Thank you for your comment. We have taken your suggestion to heart and incorporated more and more recent papers. We followed Vinodh's et al (2021) approach and distinguished between applications of digitalization/ Industry 4.0 to Lean, and to Six Sigma/LSS. We have added several more papers, including but not limited to:

Antony, J., McDermott, O., Powell, D. and Sony, M. (2023), "The evolution and future of lean Six Sigma 4.0", *The TQM Journal*, Vol. 35 No. 4, pp. 1030–1047, doi: 10.1108/TQM-04-2022-0135.

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Kumar, P., Bhadu, J., Singh, D. and Bhamu, J. (2021), "Integration between Lean, Six Sigma and Industry 4.0 technologies", *International Journal of Six Sigma and Competitive Advantage*, Vol. 13 No. 1/2/3, p. 19, doi: 10.1504/IJSSCA.2021.120224.

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Pozzi, R., Rossi, T. and Secchi, R. (2023), "Industry 4.0 technologies: critical success factors for implementation and improvements in manufacturing companies", *Production Planning & Control*, Vol. 34 No. 2, pp. 139–158, doi: 10.1080/09537287.2021.1891481.

Puvanasvar, A.P., Megat, M.H.M.A., Tang, S.H., M.R, M. and Hamouda, A.M.S. (2008), "A Review of Problem Solving Capabilities in Lean Process Management", *American Journal of Applied Sciences*, Vol. 5 No. 5, pp. 504–511, doi: 10.3844/ajassp.2008.504.511.

Rossini, M., Powell, D.J. and Kundu, K. (2023), "Lean supply chain management and Industry 4.0: a systematic literature review", *International Journal of Lean Six Sigma*, Vol. 14 No. 2, pp. 253–276, doi: 10.1108/IJLSS-05-2021-0092.

Sanchez, L. and Blanco, B. (2014), "Three decades of continuous improvement", *Total Quality Management & Business Excellence*, Vol. 25 No. 9–10, pp. 986–1001, doi: 10.1080/14783363.2013.856547.

Saxby, R., Cano-Kourouklis, M. and Viza, E. (2020), "An initial assessment of Lean Management methods for Industry 4.0", *The TQM Journal*, Vol. 32 No. 4, pp. 587–601, doi: 10.1108/TQM-12-2019-0298.

5) RQs . Are we sure they are not hypotheses? Not sure

We have named the RQs since they are answered mostly qualitatively (especially RQ2, and RQ3). Our data does not allow us to prove/disprove them.

6) Discussion is poor. We need more comparison with other recent authors who dealt with CI - LSS and I4.0

Using the newly introduced literature (see comments 3+4) we have expanded the discussion and implications for theory, linking our findings more to recent work in this area.

7) Implications for practice are very poor. in the previous sections, you have found so many possible suggestions for practitioners.

Yes, thank you for this suggestion! We have synthesized our findings to a more concrete set of steps that practitioners can apply.

Referee: 2

Recommendation: Accept

Comments:
very interesting article, consider to replace Dutch terms in tables/figures to English and some extra attention on the validity of the sample chosen for the interviews would help

Thank you for pointing this out. There is an issue with how our files are transferred to the system. For this reason and for the purpose of review, we have included them as images in the manuscript.

We have also added some additional information about how participating organizations were selected and how we defined key informants.