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Digital capabilities driving industry 4.0 and 5.0 transformation: Insights from an interview study in the maintenance domain

Mirka Kans [a,*,1], Jaime Campos [b,2]

[a] Department of Technology Management and Economics, Chalmers University of Technology, Vera Sandbergs allé 8, Gothenburg SE-412 96, Sweden

[b] Department of Informatics, Linnaeus University, Luckligs plats 1, Växjö SE 351 95, Sweden

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ABSTRACT

This study examines the role of digital capabilities in facilitating organizational transformation within the maintenance domain, focusing on the need for transitioning from Industry 4.0 to Industry 5.0. The evolving concept of Industry 5.0 complements Industry 4.0 by shifting the focus from automation to human-machine collaboration. Industry 5.0 aims to create a more cooperative relationship between humans and machines to maximize productivity and innovation. To facilitate digital transformation, companies need to develop suitable digital capabilities. Through interviews with maintenance specialists and practitioners, we identified key challenges and facilitators to implementing emerging technologies. Key findings highlight the importance of providing high-quality education, aligning digital tools with work tasks, and offering user-friendly digital solutions. Furthermore, the findings emphasize the need for robust information sharing, cooperation, and the formalization of responsibilities between maintenance and production functions. Lastly, establishing a clear digital strategy, commitment to investments, and testing new technologies are crucial for facilitating digital transformation and promoting a culture of innovation.

1. Introduction

The Industry 4.0 approach that was coined approximately ten years ago has become a worldwide-accepted term (Xu, et al., 2021). Industry 4.0 is recognized for leveraging cutting-edge technologies, including cyber-physical systems (CPS), the Internet of Things (IoT), and cloud computing, to enable smart, automated factories (Lu, 2017; Zangiacomi, et al., 2020). Moreover, it integrates digital technologies, such as big data analytics, machine learning, and artificial intelligence, with the aim to optimize production and improve efficiency (Alcácer and Cruz-Machado, 2019; Gajdzik and Wolniak, 2022; Huber et al., 2022). Hence, the goal is to prioritize the automatization of critical processes and activities in the industry. These efforts have brought about smart and intelligent organizations (Jantunen et al., 2017; Zolotová, et al. 2020). The automatization and digitalization of industry enable efficient, flexible, and decentralized manufacturing logic and self-regulating value creation (Stock and Seliger, 2016; Hofmann and Rüsch, 2017; Çınar et al., 2021; Aheleroff et al., 2021; Marcucci et al., 2022), manifested as shortened cycle times, reduced bullwhip effect, improved production planning, mass customization, and transparency in the supply chain.

Industry 5.0 is a relatively new concept that builds upon Industry 4.0 by integrating human-centric approaches with advanced technologies, emphasizing not just innovation, but also sustainability and resilience. This approach shifts the focus from purely automation to a cooperative relationship between humans and machines, enhancing human capabilities and ensuring that technology serves broader goals such as environmental sustainability and organizational resilience (Xu et al., 2021; Borchardt et al., 2022). Industry 5.0 aims to create an interdependent connection between people, where people and machines work together to achieve higher productivity, efficiency, and quality levels (Ghobakhloo, 2018). This requires developing and implementing advanced technologies such as collaborative robots, augmented reality, and artificial intelligence designed to work with humans safely and efficiently.

Successful digital transformation can serve as an enabler for sustainability and open innovation (Robertsone and Lapiņa, 2023). Robertsone and Lapiņa (2023, p. 11) define digital transformation as “an

* Correspondence to: Chalmers University of Technology, Vera Sandbergs Allé 8, Gothenburg SE-412 96, Sweden.
E-mail address: mirka.kans@chalmers.se (M. Kans).
[1] ORCID 0000–0002-2637–6175
[2] ORCID 0000–0001-7048–8089

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innovation that adopts digital technologies to completely change how companies operate, satisfy their stakeholders, and deliver value and social welfare". In this context, innovation impacts both internal business processes and the development of new products and services, highlighting the importance of fostering an innovation culture to quickly respond to evolving demands and needs. For maintenance, the adoption of Industry 4.0 technologies is poised to revolutionize and innovate practices, emerging as both a transformative force and an essential requirement. This is particularly evident as advanced maintenance strategies increasingly rely on real-time monitoring and predictive analytics enabled by Industry 4.0 technologies. These strategies not only improve equipment reliability and uptime but also contribute to better resource utilization, cost savings, and operational efficiency, closely aligning with the objectives of Industry 4.0 and 5.0 paradigms (Campos, 2009; Kans et al., 2016; Bokrantz et al., 2020; Algabroun et al., 2022; Saihi et al., 2023). Additionally, predictive maintenance can create value at the business model level (Boffa and Maffei, 2024) or foster the development of innovative business models (Kans and Ingwald, 2023).

Several applications of Industry 4.0 and 5.0 within maintenance have emerged. However, as with any digital transformation, the challenges seem to be less about finding suitable technological solutions and more about preparing the organization for change. For instance, Saihi et al. (2023) found that the main challenges to digital transformation in maintenance are strategic and organizational in nature. Moreover, the implementation of digital technologies requires not only modifying an organization's operational model but also developing and promoting modifying an organization's operational model and developing and promoting the organizational capabilities needed to manage the digital transformation effectively (Wulf et al., 2017; Dressler and Paunovic, 2021). Digital capabilities are the technical and organizational competencies, expertise, and resources a company requires to provide digital technologies with the ability to modify its operations and improve its performance (Peppard and Ward, 2016). These digital capabilities are critical for organizations looking to prosper in the digital economy, enabling them to leverage technology to achieve their business goals. Consequently, the digital capabilities in the organization are essential for a successful implementation and use of emerging technologies (Huber et al., 2022). Developing and building digital capabilities is a continuous process as digital technologies constantly evolve. Therefore, companies must continuously adapt to remain competitive (Ghobakhloo and Fathi, 2020). Although an extensive body of literature explores Industry 4.0 technologies, maturity, and readiness, research focusing on digital capabilities within this domain remains limited.

This article aims to investigate the evolving landscape of Industry 4.0 and the emerging concept of Industry 5.0, with a specific focus on the critical role of digital capabilities in driving organizational transformation. The following research questions guide the investigation:

- RQ1: What are the key enabling technologies of Industry 4.0, and how do they support organizations in developing required operations capabilities within the maintenance domain?
- RQ2: What are the challenges and facilitators related to implementing Industry 4.0 and Industry 5.0 within the maintenance domain?
- RQ3: What are the key digital capabilities required by organizations to successfully implement and leverage technologies within the Industry 4.0 and Industry 5.0 paradigms?

To address the research questions and achieve the purpose, a literature review on enabling technologies and digital capabilities was conducted to synthesize the extensive research in the field, with a focus on RQ1 and RQ3. Additionally, an interview study on challenges, facilitators, and key capabilities related to implementing emerging technologies in the maintenance domain was conducted to develop a deeper empirical understanding regarding all research questions.

The structure of the article is outlined as follows. Section 2 presents the theoretical framework, covering the concepts of Industry 4.0 and 5.0, digital transformation and digital capabilities. Additionally, this section introduces the maintenance process and its requirements for digitalization. The research methodology is described in Section 3, and the results from the interview study are found in Section 4. Section 5 discusses key digital capabilities for facilitating Industry 4.0 and Industry 5.0 transformation based on the empirical findings and theoretical framework. Finally, conclusions are drawn in Section 6 and suggestions for future research.

2. Theoretical framework

2.1. Industry 4.0 and Industry 5.0

Industry 4.0 and Industry 5.0 are built on a wide range of technologies, including cyber-physical systems (CPS), the Internet of Things (IoT), data analytics, and artificial intelligence (AI). While Industry 4.0 focuses on automation and digitalization, Industry 5.0 emphasizes human-centric approaches and sustainability, integrating advanced technologies to enhance collaboration between humans and machines (Lu, 2017; Xu et al., 2021.) In the maintenance domain, Industry 4.0 technologies such as CPS, IoT, and cloud computing enable smarter maintenance practices, including real-time equipment monitoring, predictive maintenance, and improved fault detection (Lee et al., (2015); Bokrantz et al., (2020); Bouisdekis et al., 2020; Compare et al., (2020). These technologies enhance equipment uptime and operational efficiency in smart factories.

Although researchers and practitioners commonly understand that the concept of Industry 4.0 relies on emerging technologies that enable effective, integrated, and flexible production and information flows, there are varying views on what core technologies comprise Industry 4.0 (Stock and Seliger, 2016).

In an extensive literature review of Industry 4.0, Lu (2017) identified mobile computing, cloud computing, big data, and the Internet of Things (IoT) as key technologies. Mobile computing and cloud computing serve as the backbone for data distribution through the integrated IoT. By combining these technologies, the concept of smart factories is realized. This is consistent with the findings of Stock and Selinger (2016), Hofmann and Rüsch (2017), and Marcucci et al. (2022). Big data sets provide crucial information for analysis, which, in combination with other technologies such as IoT, AI, and simulation models, support the creation and operation of Digital Twins (DT) for equipment and facilities (Lu, 2017; Alcácer and Cruz-Machado, 2019; Marcucci et al., 2022). In maintenance, big data sets are critical for creating digital twins (DT) of equipment, allowing for real-time simulations and analysis that enhance predictive maintenance and minimize equipment downtime (Alcácer and Cruz-Machado, 2019; Gebhardt et al., 2022). Advanced digital systems generate significant data from equipment, which is analyzed using machine learning (ML), deep learning (DL), and AI-driven technologies to predict failures, schedule proactive maintenance, and optimize equipment reliability (Lu, 2017; Xu et al., 2021; Azari et al., 2023).

Augmented reality (AR) and virtual reality (VR) allow users to engage with virtual environments, offering applications such as training, expert assistance for complex maintenance tasks, and product design (Rikalovic et al., 2021; Manca et al., 2013; Penna et al., 2014; Kerin and Pham, 2019). Several authors consider intelligent robotics to be an Industry 4.0 technology (Alcácer and Cruz-Machado, 2019; Zheng et al., 2021; Rikalovic et al., 2021). Some researchers also include additive manufacturing, such as 3D printing, in the list of Industry 4.0 technologies (Kerin and Pham, 2019; Zheng et al., 2021; Gebhardt et al., 2022). Additive manufacturing enables the personalization and adaptation of products. For instance, Aheleroff et al. (2021) propose "mass personalization as a service" for the production of face masks using additive manufacturing. In the maintenance domain, additive manufacturing enables efficient spare parts management, reducing both inventories and waiting times (Lastra et al., 2022).

In the context of maintenance, cybersecurity plays a crucial role in protecting the integrity of IoT-connected devices, cloud-based data storage and processing, and real-time monitoring systems, ensuring safe and uninterrupted maintenance operations (Campos et al., 2016; Alcácer and Cruz-Machado, 2019; Rikalovic et al., 2021; Laiton-Bonadiez et al., 2022). Borchardt et al. (2022) discuss various key aspects of Industry 5.0, including technological application, human resources (HR) and workers, education and training, and business and operations management. The article highlights the integration of emerging technologies and emphasizes the need for a holistic approach that considers both technological aspects and organizational dimensions to implement these technologies effectively.

2.2. Digital transformation and digital capabilities

Digital transformation refers to the utilization of digital technologies to revolutionize business processes, operations, activities, and customer experiences (Wulf et al., 2017; Zangiacomi et al., 2020). According to Zangiacomi et al. (2020), successful digital transformation requires investments in Industry 4.0 technologies, the establishment of a transformation roadmap, and knowledge sharing within and between companies. Supporting this transformation can be achieved using maturity and readiness models. It is essential to differentiate between readiness and maturity, where an organization must be ready for adaptation before it can mature (Schumacher et al., 2018; Lucato et al., 2019).

Readiness models serve as frameworks for assessing an organization's preparedness to adopt a specific technology, process, or initiative. They help identify existing barriers or gaps that might hinder the successful implementation of a new digital solution (Pacchini et al., 2019). On the other hand, maturity models are frameworks used to understand and determine the maturity level of a company in a specific domain or process associated with a particular goal. These models define the stages or levels an organization needs to achieve to enhance its capabilities and effectively implement new digital tools (Dikhanbayeva et al., 2020). Thus, readiness is a prerequisite for developing the maturity level of an organization. Several readiness and maturity models have been proposed for Industry 4.0 (Schumacher et al., 2016; Lucato et al., 2019; Sony and Naik, 2020; Nick et al., 2021). While strategy and technology are commonly covered dimensions in these models, additional internal dimensions are also included. Schumacher et al. (2016), Sony and Naik (2020), and Nick et al. (2021) incorporate dimensions such as products & services, leadership & organization, employees, and culture. Schumacher et al. (2016) cover operations, governance, and customers, while ecosystem aspects such as technology in the supply chain are included by Sony and Naik (2020) and Nick et al. (2021).

Digital capabilities encapsulate the organization's readiness and capacity to effectively leverage digital tools and technologies to pursue its strategic goals and navigate the complexities of the digital era (Peppard and Ward, 2004; 2016). According to Peppard and Ward (2004), digital capabilities are built on key resources and competencies that an organization possesses. In this respect, resources are defined as the resources an organization has under its control or at its disposal while competencies are the abilities of the organization to develop, mobilize, and utilize those resources. Building relevant capabilities requires attention to all levels of the organization: securing adequate resources at the functional level, providing relevant structures and processes at the operational level to develop competencies, and aligning competencies with objectives, investments, and strategies at the strategic level to achieve digital capabilities. The digital capability model proposed by Peppard and Ward (2004); (2016) outlines the key components, competencies, and resources required by an organization to effectively harness digital technologies and drive digital transformation, see Figure 1.

A key resource is the proficiency of employees in utilizing digital tools, encompassing their expertise and experience in both business and

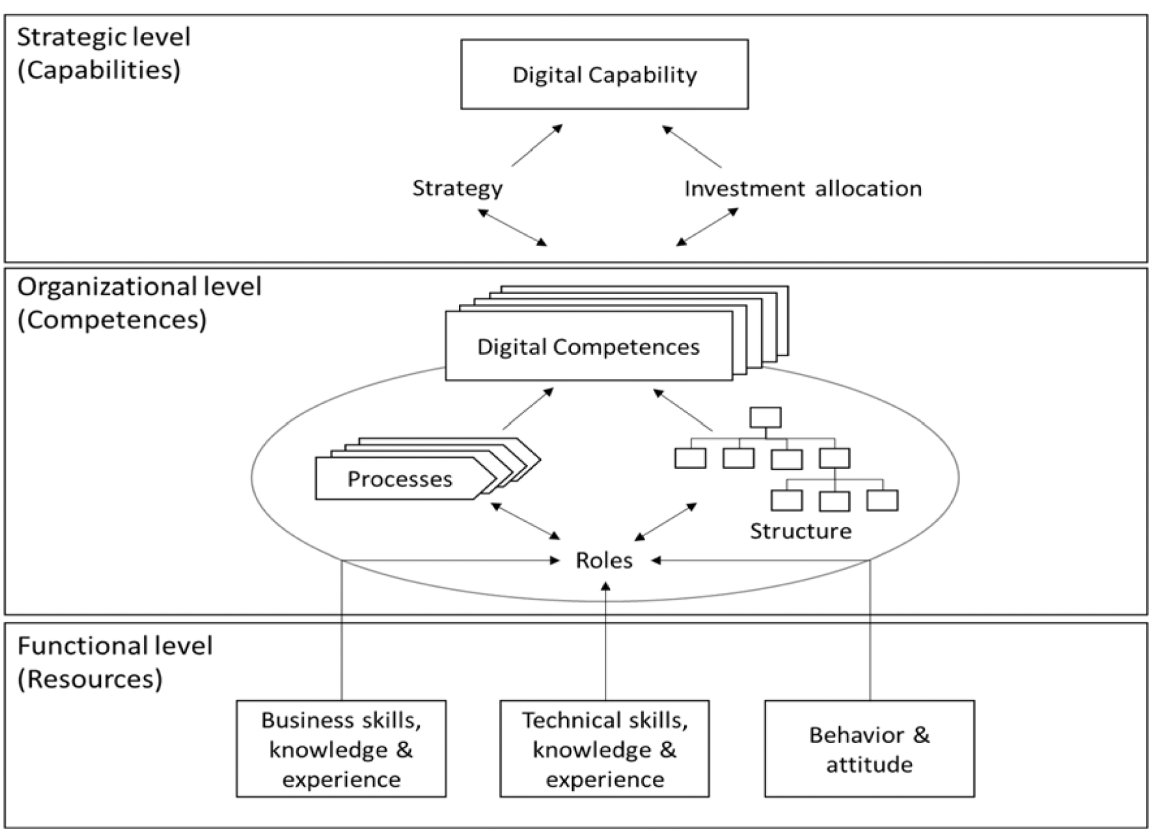

Fig. 1. Digital capability model adapted from Peppard and Ward (2004); (2016).

technical domains. Employees should have expertise, experience, domain-specific knowledge relevant to their business, and foundational technical skills. In addition, organizational flexibility requires a culture that embraces innovation, a willingness to take risks, openness to innovations, and a focus on continuous learning and improvement (Dubey et al., 2018). This is reflected in the behaviors and attitudes of individuals at the functional level in the digital capability model.

The skills and behaviors of individual employees are reflected in their roles on the organizational level. As one individual is likely to perform several different roles over their working life, the competence of individuals might change over time. The individual employees are supported by appropriate organizational structures and processes to develop the required digital competencies. According to Peppard & Ward, the contribution of digital competencies to digital capability is determined by two key factors: the organization's strategy and its investment decisions. In this regard, the digital strategy should encompass technology-related drivers, such as the development of emerging technologies, as well as business-related drivers that necessitate organizational change.

2.3. Digital capabilities related to Industry 4.0 and Industry 5.0

Müller et al. (2018) explored how small and medium-sized enterprises (SMEs) approach business model innovations in the context of Industry 4.0 and identified the main factors that influence the preparedness of SMEs for Industry 4.0. The findings indicate that SMEs need to invest in digital infrastructure, adopt a strategic orientation towards Industry 4.0, and foster an innovation culture. It is crucial for SMEs to recognize the opportunities and challenges presented by the evolving industrial landscape and to embrace suitable business models that facilitate the effective integration of digital technologies and a more human-centric approach to manufacturing processes.

Huber et al. (2022) outline three core capabilities facilitated by Industry 4.0 technologies: connecting and storing, understanding, and acting, and predicting and self-optimizing. Connecting and storing involves gathering and storing data from various sources using technologies like IoT and cloud computing, enabling informed decision-making and efficiency. Understanding and acting refers to an organization's ability to perform advanced analytics through machine learning and AI, enhancing operational insights of operations, processes, customers, and resources, resulting in increased effectiveness and optimized decision-making. Predicting and self-optimizing utilize data for future projections and real-time enhancements. These capabilities, supported by strategic, human resource, and technological elements, drive efficiency, cost savings, and improved customer experiences (Huber et al., 2022).

Ghobakhloo (2018) presents a comprehensive strategic roadmap for transitioning from Industry 4.0 to Industry 5.0 in the manufacturing sector. The study emphasizes key technologies that play an important role in both Industry 4.0 and Industry 5.0. Industry 5.0 introduces a greater focus on human-centered design, collaboration between humans and machines, and personalized production processes that are environmentally friendly. The study also identifies barriers such as insufficient understanding, inadequate investment, cybersecurity risks, legal and regulatory issues, and workforce skill gaps. The proposed roadmap includes a clear vision and strategy, evaluation of digital readiness, investment in relevant technologies, alignment of workforce competencies, effective change management processes, addressing legal and cybersecurity concerns, and continuous monitoring of progress.

Borchardt et al. (2022) underscore the significance of upskilling and reskilling the workforce, the role of HR practices in fostering worker motivation and engagement, the implications of Industry 5.0 on education and training, and the impact on business and operations management. The authors emphasize flexibility, agility, and customer-centricity as critical elements for effectively responding to evolving market demands in the Industry 5.0 era.

2.4. The maintenance process and its digitalization requirements

According to the standard EN13460 (SIS, 2009), the maintenance process could be seen as a series of interconnected activities which form a continuous workflow. Six generic maintenance activities are described in Figure 1: *Planning*, *Scheduling*, *Execution*, *Reporting*, *Analysis*, and *Improvement*. Planning and scheduling precede the release of the work order and the execution of the maintenance task. After completion, reporting is made in the Computerized Maintenance Management System (CMMS). The reports form the basis for the analysis and improvement activities. Information and documents form the input for each activity and the activity itself creates output in the form of information and documents (Kans and Ingwald, 2008, 2012; SIS, 2009; Campos, 2016). Input for planning are technical specifications, spare parts lists and drawings, and operations and maintenance manuals. For scheduling purposes, different records, and lists such as the plant register, personnel list, and spare parts and supplier register, form the basis. The results from planning and scheduling are the maintenance plan and work orders. Execution is supported by procedures for e.g., calibration, lubrication, spare parts change, and safety instructions. Reporting is made against the work order and the reports form the maintenance and asset history used as input for analysis and improvement work.

According to Aboelmaged (2015), the effective utilization of sophisticated Information and Communication Technology (ICT) tools can shift the focus of maintenance operations from reactive to predictive measures, and thereby improve the outcomes. In Figure 2, the activities emphasized by different maintenance strategies are illustrated to identify digital support and capabilities related to each maintenance strategy. Reactive and corrective maintenance strategies aim at maintenance execution after a stoppage or failure has occurred. These strategies require information for operational and short-term planning, where the business objective is to minimize the lead time from the point where a stoppage or failure occurs until it is fixed. A corrective maintenance strategy, therefore, relies on information that enables efficient scheduling of the maintenance work, such as resource availability, manuals, and procedures (Kans and Ingwald, 2008). The ability to identify and diagnose failures is also important. Reactive and corrective maintenance strategies primarily address the scheduling, execution, and reporting activities of the maintenance workflow.

Preventive maintenance aims at preventing failures by predetermined, time or operations based, activities (Ahmad and Kamaruddin, 2012). These strategies are based on predetermined maintenance activities such as inspections, lubrication, and cleaning, or change of spare parts before failures occur. The maintenance planning is based on the specifications from the original equipment manufacturer and the maintenance history. A preventive maintenance strategy addresses all activities in the maintenance workflow, emphasizing the activities from planning to analysis. Predictive maintenance strategies aim at minimizing failures, downtime, as well as maintenance time by monitoring the failure degradation and executing maintenance just before failure. Predictive maintenance strategies utilize big data sets and advanced data processing algorithms for monitoring, diagnostics, and prognostics purposes (Bousdekis et al., 2020; Algabroun et al., 2022). Both real-time process and sensor data and historical asset data are utilized. By predicting future states of equipment health and potential failure modes, this strategy enables the creation of maintenance plans aimed at either preventing or minimizing the impact of predicted failures. A predictive maintenance strategy emphasizes the activities from analysis to planning.

3. Research methodology

3.1. Data collection

Empirical data were retrieved through an interview study with Swedish stakeholders in the maintenance domain. The selection of

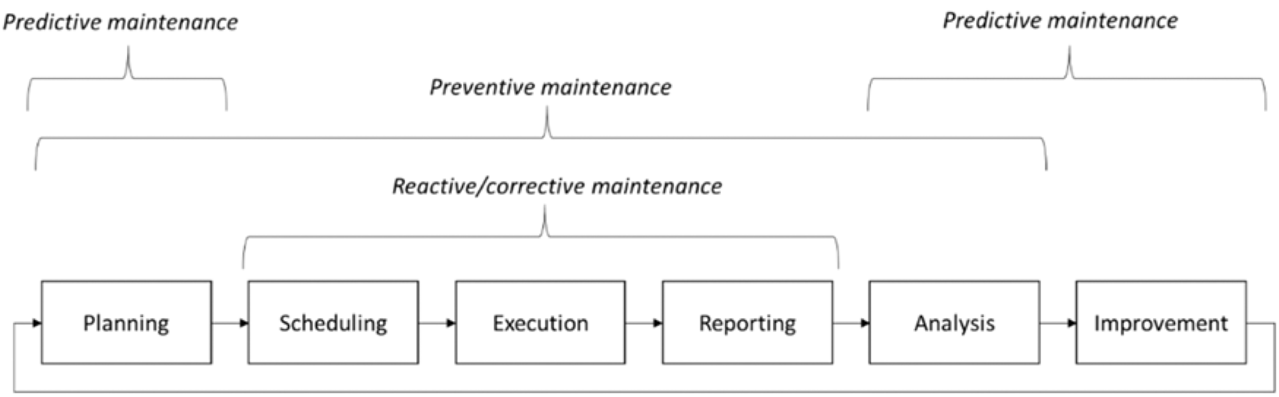

Fig. 2. The maintenance workflow and emphasize of different maintenance strategies.

interview participants was made to ensure a wide range of views covering important actors in the business ecosystem. In total, 29 interviews were carried out with representatives from producing companies, suppliers, and education and research organizations, see Table 1. Suppliers were selected to represent ICT and technology solution providers (10 interviewees) as well as consultants within maintenance and/or ICT and technology (8 interviewees).

The interview study was carried out in a two-phase mode. The first round of interviews resulted in 22 interviews with suppliers, researchers, and education representatives (Respondents #1–22 in Table 1). These interviews were conducted face-to-face. Seven additional interviews were conducted through video conference with researchers and representatives from industry (Respondents #23–29 in Table 1). The interviews, which lasted 45–60 min each, included six open-ended questions, see Appendix A. The participants were free to give other comments upon the subject as well. The questions were selected to facilitate the respondents to freely reflect on emerging technologies and their impacts in the maintenance domain not only in the present but also in the near future. Figure 3 provides an overview of actor types with their specialization included in the study.

Table 1
Study participants.

Respondent #	Position	Actor type	Specialization
1	Senior asset management consultant	Supplier	ICT consulting services
2	CEO	Supplier	ICT solutions
3	Reliability consultant	Supplier	Maintenance consulting services
4	Production and facility manager	Supplier	Maintenance consulting services, ICT consulting
5	Technology teacher group leader	Educator	Engineering education
6	Solution consultant	Supplier	ICT solutions
7	Junior researcher	Researcher, Educator	University
8	Consultant	Supplier, Educator	Maintenance consulting services, Education
9	Seller	Supplier	Technology solutions
10	Owner	Supplier	Technology consulting
11	Department manager of service	Supplier	Maintenance consulting services, technology consulting
12	Seller	Supplier	Technology solutions
13	Junior researcher	Researcher, Educator	University
14	Researcher	Researcher	Research institute
15	Seller	Supplier	ICT solutions
16	Product/department manager	Supplier	Maintenance consulting service
17	Marketer	Supplier	ICT solutions
18	Marketing, sales, training	Supplier	ICT solutions
19	Regional manager Scandinavia	Supplier	Technology solutions
20	Seller	Supplier	ICT solutions
21	Sales manager	Supplier	Technology solutions
22	Consultant	Supplier	Maintenance consulting services
23	Professor	Researcher, Educator	University
24	Professor	Researcher, Educator	University
25	Research manager external cooperation	Producer	Chemical industry
26	Maintenance responsible at the group level	Producer	Automotive industry
27	Maintenance manager	Producer	Wood industry
28	Manager of reliability & future factory	Producer	Manufacturing industry
29	Responsible for technology, projects and ICT (Operations)	Producer	Paper industry

3.2. Data analysis

Deductive content analysis and thematic analysis were performed on the data set. Deductive content analysis involves structuring the analysis based on existing knowledge with theory testing as the main aim (Elo and Kyngäs, 2008). The analysis covers the activities of preparation, organizing, and reporting. In the preparation phase, the unit of analysis is selected, and a holistic understanding of the data set is gained. Thereafter, an analysis matrix is created that facilitates the coding of data. The outcomes are compared with previous studies, leading to new conceptualizations.

An initial content analysis was conducted, in which enabling technologies (Lu, 2017; Alcácer and Cruz-Machado, 2019; Rikalovic et al., 2021) were related with activities in the maintenance workflow (SIS, 2009; Kans and Ingwald, 2012), and challenges and facilitators for implementing Industry 4.0 technologies were related with readiness and maturity aspects (Schumacher et al., 2016; Sony and Naik, 2020; Nick et al., 2021). The content analysis provided the authors with valuable insights regarding the data set and the possibilities to make further analyses with respect to digital capabilities. The findings from the content analysis are not accounted for in this article.

In the next step, thematic analyses were performed for achieving a holistic understanding of the data set with respect to digital capabilities. In the thematic analysis, the enabling Industry 4.0 technologies supporting maintenance workflow activities were aligned with components of digital capabilities according to Huber et al. (2022). Thereafter, challenges and facilitators for implementing Industry 4.0 technologies

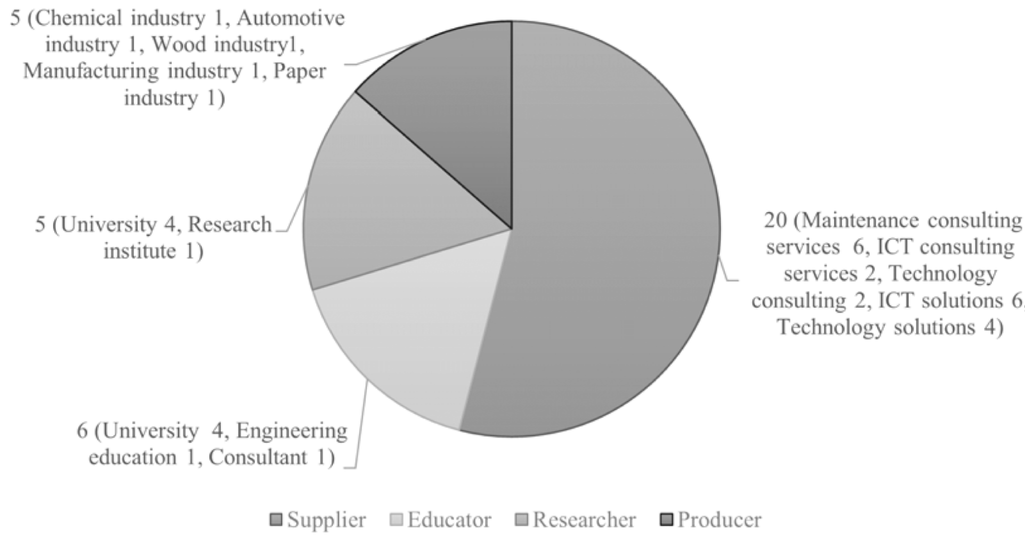

Fig. 3. Actors included in the study.

within the maintenance domain were aligned with components and levels of digital capabilities according to Peppard and Ward (2004); (2016). This model is comprehensive in that it addresses key organizational and strategic aspects, as well as the essential competencies required to support a technology transformation within the organization. Although technologies may evolve or change, the model encompasses the generic aspects of an organization.

4. Main findings

In this section, the findings are organized around two primary themes derived from the analyses outlined in Section 3.2. A summary of the main findings concludes each section. Quotes from participants are provided in Appendix 2 to highlight key points.

4.1. Enabling Industry 4.0 technologies within the maintenance domain

4.1.1. Enabling technologies of today

Connecting and storing is, according to the interview respondents, the Industry 4.0 capability that drives the current development within maintenance. Capabilities connected to understanding, acting, predicting and self-optimizing are also seen as important by the respondents, but it is recognized that, to reach these capabilities, the basic connecting and storing capabilities must be at hand.

The ability to retrieve and store relevant information for open access is a key to success. This could be in the form of a data lake, information cloud, or integrated holistic IS solutions that are reachable by several functions. Without a relevant accessible database, the information could not be analyzed and used for decision-making. Access to data both today and in the future is important. By saving all the data, one respondent explains, you have a basis for analyses you might not have thought of when you installed the systems. The CMMS is seen as an important and obvious basic technology that should be integrated with or supplemented by other applications. Several respondents mention Big Data Analytics, Artificial Intelligence and Machine Learning as key technologies, as they can help the organization in becoming more preventive. Data analysis capabilities are primarily important for deviation detection and predictive maintenance, and for improving the business.

Accessibility relates to the ability to communicate and connect. According to the respondents, mobile devices and IoT technologies are the main enablers. Well-functioning wireless networks using 4 G and 5 G technologies are also deemed important. As an example, one respondent concluded that sensors need to be able to communicate and described the highly automated monitoring of operations at the plant using smart sensors connected through 4 G and 5 G.

4.1.2. Enabling technologies in five years' time

While connecting and storing is seen as a main enabling capability of today, understanding, acting, and predicting are the enablers in the future, according to the respondents. In five years, it is foreseen that Big data analytics, AI and ML will be supporting the decision-making process. In addition, visualization supports the planning of maintenance activities as well as the follow-up and improvement work.

Mobile devices and communication technologies support the information retrieval and utilization process and make the decision making more flexible. The connectivity of machines and equipment is important, but in the future, enabling technologies connect humans as well.

Augmented reality and metaverse applications are also seen as enablers in the future. AR is used for fault detection and troubleshooting, and for receiving expert support when executing work, i.e., AR is supporting the maintenance execution activities. Self-optimizing capabilities are foreseen primarily in the form of automated decision making. Automation of operations are mentioned by some respondents in the form of wireless or integrated sensors for data capture or drones and robots for condition monitoring. The concept of self-healing machines was also mentioned by one respondent. Even though many respondents foresee a positive development, some express concerns regarding the implementation of Industry 4.0 technologies.

4.1.3. Results summary regarding enabling Industry 4.0 technologies

Table 2 summarizes the key enabling technologies of today and in five years' time, according to the interview respondents. It should be noted that a specific enabling technology may be considered important both today and in the near future. Consequently, some technologies are marked as enablers for both the present and within five years' time.

Today, the establishment of an integrated and shared information base is crucial. The gathering of real time process and maintenance data using sensor technology and IoT as well as seamless information sharing through mobile devices and integrated systems, is seen as important today as well as in the immediate future. Notable is that technological solutions are expected to advance; sensors will become more advanced and wireless and the connections will be faster using 5 G and 6 G technologies in the future. Main part of the respondents had a positive attitude towards advanced data analytics for maintenance planning and decision-making. The main application areas of today are condition-monitoring, deviation analysis, and preventive planning, while

Table 2
Enabling Industry 4.0 technologies.

Enabling technology	Today	Five years' time
Connecting and storing		
Information storage using internet technology	x	
Real time data retrieval through sensor technology, and the similar	x	x
Online communication technology such as high-speed wireless technology, IoT, machine-to-machine communication, and the similar	x	x
Information sharing through mobile devices and system integration	x	x
Understanding and acting		
Advanced data processing through big data analytics, AI, ML, and the similar	x	x
Advanced preventive planning and decision support	x	x
Information visualization	x	x
Cyber-physical systems through digital twins, metaverse, and the similar		x
Predicting and self-optimizing		
Forecasting and prediction		x
Self-monitoring and healing machines		x

forecasting, prediction, and self-optimization are capabilities of tomorrow.

4.2. Factors affecting the digital transformation within the maintenance domain

4.2.1. Functional level

On the business function level, skills, competences, attitudes, and behaviors affect the digitalization process. The lack of relevant competences is a major hindrance to the digital transformation of maintenance, according to the respondents. Business and technical skills were seen as prerequisites for developing a digital capability in maintenance. The ability to specify requirements and manage the procurement process when investing in innovative technology was also seen as important, which makes use of both business skills like understanding failure mechanisms and failure degradation processes, as well as digital skills for understanding what technology solution could be applicable for failure detection, diagnosis, and prognosis. This could, for instance, be the ability to understand whether a specific sensor technology is applicable for measuring a specific failure mode.

Several respondents addressed the dire need for digital and technology skills. Education, both external and internal, is seen as a means to overcome the lack of digital skills. The need for relevant and high-quality education at high school, university, and vocational level was addressed. Other suggestions were internal supervisors, and to attract newly educated and young people. For the best outcomes, the training facilities must be adapted to the emerging technologies. An aging workforce makes the digital transition challenging, especially with respect to training and education. An alternative is, therefore, to acquire the skills by employing new people. The respondents find this the biggest hindrance as well as the best way to overcome the lack of digital skills and competences. In particular, the hiring of young people is desired.

Another way to approach the lack of digital skills is to redesign the technology for better user experience. This requires cooperation between the suppliers and the customers. Many respondents view people as the main problem, though. There are suitable technological solutions available, but the low digital competence in combination with unpreparedness for adapting emerging technologies hampers the implementation. Low preparedness is reflected in low technology awareness as well as low technology trust. In addition, there is a fear of how technologies will affect working conditions. Data collection activities, for instance, are often added to the responsibilities of operators and technicians. If this is done without proper motivation or allotting time, it might result in a monotonous execution endangering the data quality. In the worst case, misinformation about technology implementation could lead to fear of losing the job.

4.2.2. Organizational level

On the organizational level, the processes and structures affect the digital transformation in both positive and negative ways. Processes are socio-technical systems, in which humans and technology interact and are coordinated through information systems.

In the interview study, the complexity in the production process was pointed out as problematic. This affects the possibilities to coordinate activities within and between processes, such as the core production process and the maintenance supporting process.

Poorly integrated information systems are a hindrance to achieving efficient processes. Integrated information systems enable cross functional information sharing and cooperation. Cooperation is a key to successful digital transformation, according to the respondents. The digital transformation affects the current processes and structures; we need to learn new ways to do things. Management support is a key aspect for the successful formulation and implementation of the improvement strategy.

Function orientation is seen as a big hindrance for effective implementation of digital solutions. This leads to poor alignment of maintenance objectives with the operations strategy, and poor coordination of production and maintenance related activities and plans. As a result, maintenance is not linked to production needs. In the worst case, it is instead "ordered" internally from maintenance itself. To counteract this, it is important to formalize the relationship between the production, acting as the customer or client, and maintenance, acting as the supplier of maintenance services. In addition, the business culture could be enforcing or conserving function orientation. Except for the above-mentioned hindrances, this creates difficulties in data sharing and inability to create a learning organization, as knowledge is not commonly shared. A matrix or decentralized organization structure could be a solution to the problem. Other suggestions stress the importance of alignment between the various levels in the management hierarchy. Several respondents recognize the need for a holistic view and cross functional communication for managing improvement and digitalization implementation projects.

Technology resistance is not only seen at the functional level. Managers as well can be reluctant to engage in or initiate digital improvement initiatives. Most respondents mention the aging workforce as a main hindrance, but as respondent #21 pointed out, all younger managers are not open minded towards digitalization.

4.2.3. Strategic level

Having an established strategy and roadmap for the digital transformation is seen as important. The investments should align with business needs, and a step-by-step process should support the digital transformation until the change is thoroughly founded within the organization. The digitalization strategy should cover both existing technologies and systems and the investment in emerging technologies. The digital strategy must include means to manage attitudes and provide motivation for change, so that a culture of continuous improvements is established.

While strategies and road maps are important, freedom and flexibility to test innovative ideas and technologies is also seen as crucial. The first step in digital transformation might be to carry out pilot projects, which increases the interest in emerging technologies within the organization. Digital transformation requires allocation of time and financial resources for the investment. The unwillingness to invest in the digitalization of maintenance was seen as a major hindrance by the respondents.

As one respondent points out, large benefits are to be seen with digitalization not only within maintenance but also in the overall performance of the operations. The greatest value to digitalize within maintenance are, according to the interview respondents, better decision-making capabilities, improved maintenance execution output, and increased safety. Better decision-making capabilities is a combination of the ability to measure so more data can be analyzed leading to better information overview, plannability, increased control, and predictability, and decision making in real time supporting the ability to react and adapt to changes. A more efficient maintenance function leads to increased productivity and operational reliability, improved quality assurance and traceability, and sustainable production, factors that enhance the profitability and competitiveness of the company.

4.2.4. Results summary regarding factors affecting the digital transformation

Table 3 lists the factors identified by interview respondents as either challenges or facilitators. Notably, some factors were perceived as both a challenge and a facilitator; while certain factors present challenges, addressing them effectively can also turn them into drivers of digital transformation.

At the functional level, lack of knowledge and skills are the main identified challenges, along with low technology awareness and trust. This depicts a situation of low functional as well as organizational preparedness for digital transformation. Facilitating factors at the functional level include securing the supply of trained and competent personnel by providing high quality education and internal training possibilities. To approach the distrust in technology, the digital tools should be user friendly and aligned with the main work tasks, and not result in additional workload for the employees. At the organizing level the lack of supporting structures and processes for improvement and change work, cooperation, and information sharing are seen as the main challenges, which is reflected in the organizational culture. Formalization of responsibilities, especially between maintenance and production, as well as information sharing, and cooperation are means to enable digital transformation. At the strategic level, the main challenges identified are an unwillingness to invest and the lack of a digital strategy, while daring to test new technologies and providing sufficient resources for investments are seen as crucial for facilitating digital transformation.

Table 3
Factors affecting the digital transformation.

Factor	Challenge	Facilitator
Functional level		
Maintenance domain knowledge and skills	x	
Digital knowledge and skills	x	
Technology procurement skills	x	
Acquiring combined knowledge and skills	x	x
Attracting younger people	x	x
Aging workforce	x	
Education (company internal and external)		x
User friendly technologies and systems		x
Technology awareness	x	
Technology fear/trust	x	x
Motivation to use technology	x	x
Organizational level		
Change management	x	
Process complexity	x	
System integration	x	
Cooperation and networking	x	x
Information and knowledge sharing	x	x
Organizational culture	x	
Formalization of responsibilities		x
Organizational governance		x
Strategic level		
Digitalization strategy	x	
Long term commitment	x	
Daring and testing		x
Digital governance		x
Investment willingness	x	x

5. Key digital capabilities for facilitating the transformation towards Industry 4.0 and 5.0

Prior to embarking on Industry 4.0 and 5.0 initiatives, it is imperative to consider several crucial aspects, including conducting a digital readiness assessment, establishing a well-defined vision and strategy for the organization and its operational functions, providing necessary structures and processes, understanding the role of crucial technologies in enhancing the predictiveness and proactivity in planning, and addressing human resource education, training, and development. The following section discusses digital capabilities for facilitating Industry 4.0 and Industry 5.0, drawing on previous research and the empirical findings of this article. Key capabilities are identified in accordance with the digital capability model by Peppard and Ward (2004); (2016). This model is extended with three components—innovation, culture, and technology solutions—derived from the empirical findings of the interview study (see Figure 4). The added components are highlighted in gray.

For an agile organization, it is crucial to have relevant resources available. The lack of human resources is a major challenge for effective digital transformation according to the interview study. An aging workforce and the general lack of business and digital skills and knowledge calls for a strategic plan for developing the existing workforce and for acquiring the resources externally. The importance of human capital for reaching Industry 4.0 is acknowledged in e.g., Sony and Naik (2020), Nick et al. (2021), and Huber et al. (2022), and within the maintenance domain by Bokrantz et al. (2020), and Azari et al. (2023). In the interview study, the ability to identify and formulate requirements for technology procurement was also mentioned. Continuingly, behaviors and attitudes affect successful transformation. This is recognized in previous research (see for instance Nick et al., 2021; Huber et al., 2022) as well as in the interview study. Technology is seen as an enabler and a resource for reaching Industry 4.0 (Lu, 2017; Zangiacomi, et al., 2020; Marcucci et al., 2022), while the interface between humans and technology is the main theme of Industry 5.0 (Xu, et al., 2021; Borchardt et al., 2022). In the interview study, emerging technologies were seen as a way to develop and improve maintenance practices. In addition, the importance of aligning the technology solutions with main work tasks and providing user-friendly systems that are easy to learn and manage was emphasized. The respondents pointed out the responsibility of the suppliers to ensure the usability of the technology solutions. The importance of supplier collaboration was addressed in Weyer et al., (2015), who suggested a modular production system for managing multi supplier integration. To reflect the importance of emerging technologies for the successful transformation towards Industry 4.0 and 5.0, the component of *Technology solutions* was added to the functional level.

At the organizational level, the process complexity affects the Industry 4.0 implementation according to the interview study. The importance of integrating ICT systems for achieving better control of organizational processes and facilitating the Industry 4.0 implementation was recognized by Sony and Naik (2020). Management was seen as an enabling role in the interview study that could facilitate cooperation and information between different processes. This is in line with e.g., Huber et al., (2022). A major barrier mentioned was the function orientation that exists in many companies. Organizational structures and processes facilitating the Industry 4.0 implementation are mentioned as success factors by e.g., Schumacher et al. (2016), and Ghobakhloo (2018), and is recognized as important for Industry 4.0 implementation in the maintenance domain by Bokrantz et al. (2020), Samadhiya et al. (2024), and Saihi et al., (2023). The required strategic approach to innovation will fail if the organization cannot operationalize the efforts in the processes and structures. Thus, the innovation culture is effectuated on the organizational level in the form of a culture of cooperation and continuous improvement. The importance of cooperation, information sharing, and change management for Industry 4.0

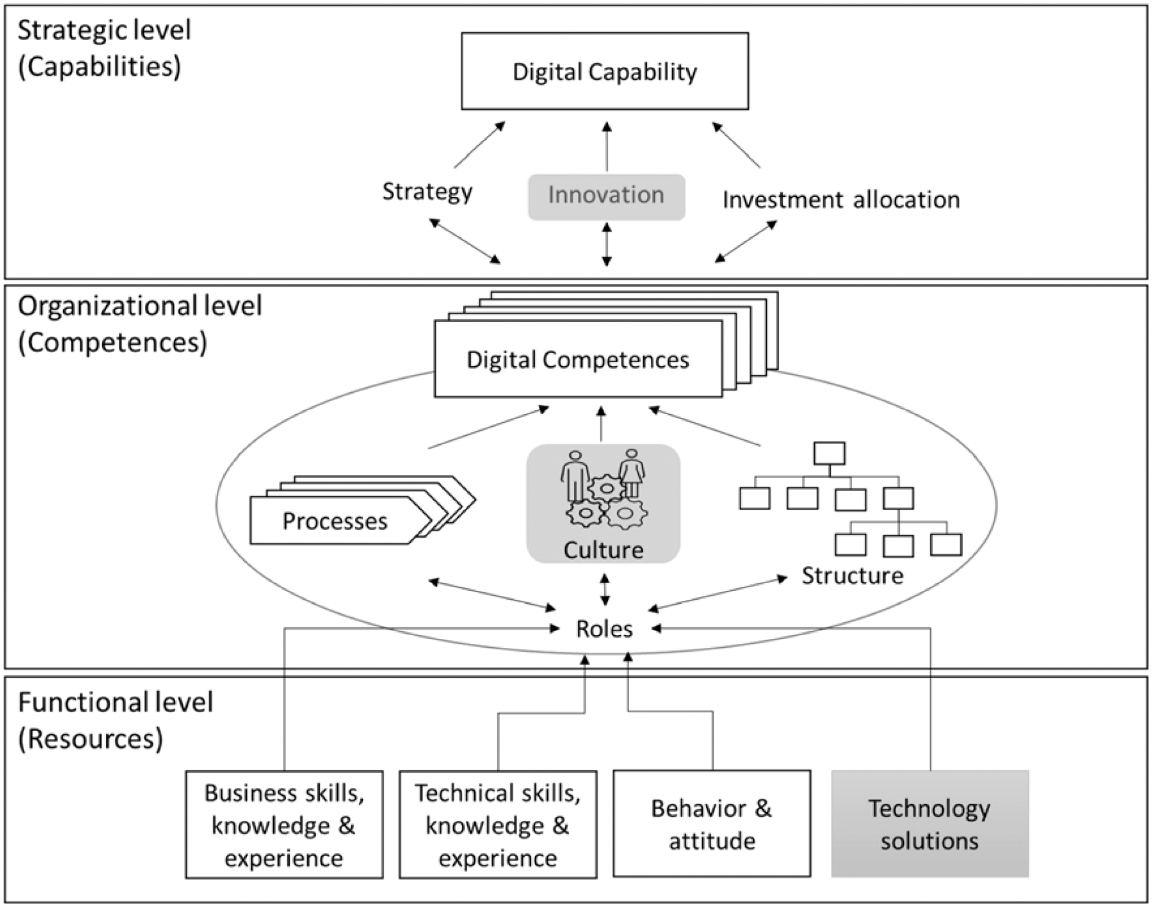

Fig. 4. Digital capabilities for facilitating Industry 4.0 and Industry 5.0.

implementation is addressed in for instance Huber et al. (2022), and Gebhardt, et al., (2022), and was seen as main facilitators in the interview study. To reflect the importance of cooperation, information sharing, and continuous improvement for creating a learning organization, the component of *Culture* was added to the organizational level.

The degree to which resources and competencies contribute to digital capabilities is contingent upon the organization's strategic direction and investment choices, see for instance Lu (2017), Ghobakhloo (2018), Huber et al. (2022), and Saihi et al. (2023). In the interview study, the lack of a digital strategy, long-term commitment, and unwillingness to invest were seen as major challenges. These factors are confirmed as important in previous research regarding Industry 4.0 implementation in general (Sony and Naik, 2020; Nick et al., 2021) and within the maintenance domain (Compare et al., 2020; Samadhiya et al., 2024; Saihi et al., 2023). The vision and strategy component necessitates the organization delineating a lucid vision for its objectives with digital technologies in the maintenance domain. This vision should be congruent with the organization's overarching business strategy and goals. Subsequently, the organization can devise a specific strategy for implementing digital technologies in maintenance operations. A strategy should continuously be assessed and changed to keep the strategic fit to achieve digital flexibility (Dubey et al., 2018). This was recognized in the interview study as the need for digital governance. Once a strategy is established, financial investment allocation is a precondition for digital transformation, but the allocation of resources for implementation is also crucial. The need for adequate investment and implementation support for Industry 4.0 is addressed in e.g., Zangiacomi et al. (2020), Nick et al. (2021), and Çınar et al. (2021). A well-formulated strategy and sufficient allocation of financial and other resources is not enough to facilitate the transformation. A mindset towards daring and testing, with the possibility of failure, was mentioned as important in the interview study. It is important to start the transformation, to *'do something'*. For this, an approach to and culture of innovation characterized by action and boldness is required, see e.g., Müller et al. (2018). This is in line with the concept of organizational agility, i.e., the ability to respond quickly and effectively to changes (Walter, 2021). To reflect the importance of acting on change for the successful transformation towards Industry 4.0 and 5.0, the component of *Innovation* was added to the strategic level.

6. Conclusions

In this article, we explored the key enabling technologies of Industry 4.0 and how they support the development of operational capabilities within the maintenance domain. Three research questions guided the investigation: 1) What are the key enabling technologies of Industry 4.0, and how do they support organizations in developing required operations capabilities within the maintenance domain?, 2) What are the challenges and facilitators related to implementing Industry 4.0 and Industry 5.0 within the maintenance domain?, 3) What are the key digital capabilities required by organizations to successfully implement and leverage technologies within the Industry 4.0 and Industry 5.0 paradigms?

Based on the interview findings, maintenance organizations should prioritize establishing an integrated and shared information base, real-time data retrieval, and seamless information sharing through mobile devices and integrated systems. This will enable them to gather and utilize data effectively for maintenance planning and decision-making. Additionally, organizations should invest in advanced data analytics capabilities to enhance maintenance practices. Condition monitoring, deviation analysis, and preventive planning are important application areas today, but organizations should also focus on developing capabilities in forecasting, prediction, and self-optimization for future needs.

Several factors were identified as challenges or facilitators for digital transformation in the maintenance domain. Functional challenges include the *lack of knowledge and skills,* and problems in *recruiting. Low technology awareness*, *trust*, and *motivation* were also identified as challenges. Facilitators cover actions to reduce these challenges by *education*, *increasing motivation* and *lowering technology fear*, and *user-friendly technology* solutions. On the organizational level, *process complexity*, *lack of supporting structures and processes*, and a *function-oriented culture* pose challenges. *Cooperation, networking* and *information sharing*, as well as *formalized responsibilities* and *organizational governance* were seen as facilitators. On the strategic level, challenges include the *lack of a digital strategy*, the *unwillingness to invest*, and the need for a *long-term commitment*, while *testing new technologies,* allocating resources and *investment capital*, and *digital governance* were seen as facilitators. It is concluded that the interview results mainly depict a situation where industry has not yet reached the full benefits of I4.0 and 5.0, and where the implementation is yet a struggle. In this respect, creating the ICT core and installing sensor technologies may be seen as a natural step before widely implementing IoT, CPS, digital twins, etc.

Successfully implementing Industry 4.0 and 5.0 requires an integrative approach that encompasses technological, strategic, organizational, and human resource factors. The transformation towards Industry 4.0 and 5.0 goes beyond merely adopting technology; it necessitates a cultural shift towards innovation, collaboration, and continuous improvement to unlock the potential of advanced technologies in maintenance operations fully unlock the potential of advanced technologies in maintenance operations fully. In this article, we adopted a digital capability perspective for facilitating the transformation and achieve alignment of the Industry 4.0 and 5.0 implementation, and key digital capabilities on functional, organizational, and strategic levels were identified. On the functional level, *business and technical knowledge and skills* are crucial resources, fostering positive *behavior and attitudes* toward emerging technologies. In addition, suitable *technology solutions* are necessary. Building trust in technology is essential, and suppliers should be proactive in ensuring the usability and user-friendliness of their solutions. User-friendly technologies and systems should be prioritized to encourage employee adoption and minimize resistance to change. The technology solutions implemented should align with the main work tasks and not result in additional workload for employees. Competences are built by adopting suitable *processes* and *structures* on organizational level. Continuingly, the *culture* affects the implementation. Organizational structures and processes should be designed to facilitate cooperation, information sharing, and change management. It is important to break down functional silos and foster a culture of collaboration and continuous improvement. Formalization of responsibilities, particularly between maintenance and production, can enhance the integration of systems and processes. Human resource development is crucial for successful digital transformation. Therefore, organizations should invest in training and education programs to develop the workforce's necessary digital skills and knowledge. This includes attracting younger talent and addressing the challenges posed by an aging workforce. On a strategic level, organizations need to develop a clear *digitalization strategy* and demonstrate long-term commitment to digital transformation. This includes a willingness to *invest* in technology and test new solutions. Digital governance should be established to ensure the strategy is effectively implemented and supported throughout the organization. Additionally, a dynamic and open *innovation* culture should be promoted. Developing these key digital capabilities paves the way for achieving Industry 5.0.

In conclusion, the authors acknowledge that the relatively small number of interview participants might limit the generalizability of the study. Although efforts were made to ensure diversity in selecting experts, future research with a larger sample size and broader industry representation is recommended to validate and expand upon these findings.

6.1. Further research

Overall, there is a need for ongoing research to keep pace with the evolving landscape of Industry 4.0 and Industry 5.0 technologies. Further studies on the human-machine interface and the impact of emerging technologies on the workforce can provide insights into how organizations can effectively leverage these technologies to improve collaboration and productivity. By addressing these research gaps, organizations can better understand digital transformation's potential benefits and challenges and make informed decisions in their implementation strategies.

More research on digital transformation's organizational and cultural aspects is also suggested. Understanding the factors that facilitate or hinder the implementation of digital technologies in maintenance, such as change management, cooperation, and information sharing, can provide valuable insights for organizations seeking to navigate transformation challenges. This study was conducted within the maintenance domain, with limited possibilities for generalizability. Extending the research to other domains and industries would therefore be of interest.

Additionally, the findings have implications for future research on digital transformation in the maintenance sector. Further studies could explore the specific impacts and benefits of Industry 4.0 and Industry 5.0 technologies on maintenance operations, such as the effectiveness of predictive maintenance strategies and the optimization of processes through advanced data analytics. Moreover, research could focus on developing and evaluating training and education programs to enhance the digital skills and knowledge of the maintenance workforce. Finally, investigating innovative approaches to attract and retain young talent in the maintenance field could also be a fruitful area of research.

Ethical Approval

Ethical approval is not applicable for this article

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Mirka Kans: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Jaime Campos:** Writing – original draft, Formal analysis, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used Chat GPT in order to improve the grammar and language of the article. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. . Interview questions

1. Which technology do you view as the most important today for developing maintenance, and within which area (planning, scheduling, execution, follow-up, improvement of maintenance)?
2. Which technology has made its breakthrough in five years' time, and which area has developed most?
3. Which are the biggest digital challenges in maintenance?
4. How can digital development best be facilitated?
5. What is the main reason and the greatest value to digitalize within maintenance?
6. Imagine the scenario that we achieved full Industry 4.0. What new challenges will we encounter?

Appendix B. . Quotes extracted from the interviews

Topic	Quote	Respondent #[1]
Enabling technologies of today	Digitization is a prerequisite for AI to work.	24
	We will save ALL data. What we guess today, we get wrong tomorrow. We save everything we can in a data lake.	29
	IoT, AI, something to supplement the CMMS.	15
	Most exciting [thing] right now is AI. To recognize patterns…and then the CMMS is needed.	17
	…data-driven, to be able to manage and analyze data, maintenance engineers to see trends, to be able to move from breakdown to preventive maintenance…	8
	Today, I would say Big Data and analytics is most important. Because we lose potential improvements…we need to make good decisions.	25
	Any given technology that provides possibilities for communication. Access to information on mobile devices.	7
	You should be able to integrate machines and machine data from many systems. Process optimization, not only on one machine.	12
Enabling technologies in five years' time	Would be good with smart forecasting and predictability. The predictability in the prognoses is more extensive, more natural.	22
	Prediction, AI engines, digital solutions that troubleshoot, think, and analyze. A lot in life that controls e.g., technology that tells you when you have been sitting for too long. In 5 years, certainly//….//Better decision-making basis, complete digital twin.	27
	To understand the data and the data processing as a decision maker. E.g., MS Power BI, where you can develop your own charts etc. People can see the entire process.	7
	Information down to the one who should receive it. You talk a lot about big data now; in 5 years' time we got quality correct data to the right person.	10
	To be a bit more mobile and have digital solutions in place.	14
	Technology where you can stand on site and see problems, facetime connection to talk to the plant at home, to receive information, drawings etc.	11
	3d-glasses, so you can scan the machine in case of failure and get expert support and support for the execution.	4
	Everything within Industry 4.0 will develop. But many are not yet ready, very low digitalization level even after 10–15 years. The maintenance process might look different when you can plan better. Today, we gather a lot of data but what should we use it for…	5
Factors affecting the digital transformation within maintenance on functional level	…be able to procure. Talk about what we want, what we want to know based on different failure mechanisms.	26
	Poor digital knowledge. Maintenance is less mechanical and more digital.	5
	Digital competence. Many are skilled at mechanics, electrics, etc. but for complex technology the competence is lacking, and maintenance is an area that needs development and technology.	14
	The learning platform must be dynamic, adapted for new technology.	18
	Education, especially for those who are not used to digitalization. To be able to use smart phones and to have data available. All maintenance technicians should have some understanding of [the emerging technologies] e.g., robots.	5
	Many people who are involved in maintenance are older, and do not understand digitalization.	23
	The young people often have the skills we are looking for. The problem is the combination of traditional maintenance…combined with IT competence. Traditional maintenance must be combined with IT competence.	28
	User friendliness, make it simpler and not more complex. The user needs to be in focus. The solution is for the end user, not for the economist.	2
	Suppliers that make things pedagogical, talk in the correct way. Finding the right ambassadors at the customer side, a lot of lobbying.	17
	Technology has come far, but not the adaptation; people are not ready. For instance, trust. The implementation phase is all about trust, especially for end users.	6

(*continued on next page*)

(*continued*)

Topic	Quote	Respondent #[1]
	Predictive maintenance, for instance, we expect the algorithm to crunch a lot of data and give one answer. It could predict, to a certain extent, e.g., 60 % and then we need to support it with human interference, the remaining 40 % must come from people. We cannot expect too much and say that digital technology does not deliver.	26
	Administrative tasks are mainly forced on us, and we should get something back from it.	3
	It is important to gain an understanding of why to use the technology. Added value in work. Aligning in the business.	26
Factors affecting the digital transformation within maintenance on organizational level	Complexity in production; several machines, flows, products.	25
	Integration, you should feel like you have one system, and not ten.	20
	Cooperation and networking. To work together to find solutions, to develop standardized solutions.	16
	Transformation comes with a lot of adaptations and opting the way of work.	25
	Continuous improvements. The management often says, "this is good", and then it is assumed that it will run in the organization without preparations.	1
	Production orders maintenance but maintenance does not get time to execute maintenance from production//…//To formalize the maintenance mission and direct the division of responsibilities between customer and supplier.	3
	Organizational culture creates barriers. This leads to knowledge being missing.	7
	…not wanting to share data.…Understanding the process from a holistic view. Culture of firefighting.	13
	Also culture - knowledge sharing. The IT department and maintenance department must have a good discussion.	26
	Communication. We who want to send information must find ways to do so. Respect the hierarchies and to get the managers involved.	10
	Organizational: Central ownership and local engagement.	15
	A few years ago, the IT department was working with Industrial IT. Now we have a department with manufacturing engineers that works with Industrial IT.	25
	The manager of 50+ years does not believe in digitalization.	10
	Generational change. 'We have always done it this way; this is how we will do'. In Europe, new younger managers are a problem. The managers of the next generation are not open for digitalization.	21
Factors affecting the digital transformation within maintenance on strategic level	Why should we have AI, Industry 4.0, Industry 5.0? If we can't answer those questions, we can't have the right strategies.	24
	To carry through the whole way. //…// Many lack the patience to finish and believe that the solution takes care of everything.	2
	Invest in the right technology. Governance and management; to have a modernization plan for hardware, EOL, etc. Since the year 2000, we have a 10-year plan to take care of the technology, a modernization plan.	29
	To land in organizations, culture. Improvement work. You need to start at the top to be able to lead change.	9
	To dare. We are so cautious. We believe we need to do everything. Give free hands, do not be so cautious.	1
	To dare to test, to be innovative.	22
	Be open to new technologies, "proof of concept". Don't take chances but be willing to evaluate the technologies yourself.	27
	Willingness to invest. The maintenance manager must get support and a budget.	9
	The willingness to invest of the upper management. To take maintenance seriously, a good maintenance organization and maintenance program saves and improves.	19

[a]Respondent # corresponds to respondent numbers listed in Table 1.

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