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Implementing and using smart maintenance technologies: Introducing challenges and enablers related to human, organizational and technological perspectives

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Abstract

Research within smart maintenance has become a popular research topic largely focused on how the nine technologies of Industry 4.0, such as Industrial Internet of Things (IIoT) and Augmented Reality (AR), as well as Artificial Intelligence (AI) and Cyber Physical System (CPS), can be used for, e.g., condition monitoring of equipment, remote services, modelling wear of components, calculating Remaining Useful Life (RUL) and prediction of failure. Due to the new generation of maintenance, new skills are required regarding the interaction between humans and technologies. Human-technology interaction in smart maintenance research is not highlighted in a structured way and according to any type of socio-technical system. The aim of the paper is to study the challenges and their associated theoretically grounded enablers regarding the implementation of and use of smart maintenance technologies, through the interplay between humans, technologies and organizations. The paper is based on empirical data from seven large manufacturing companies in Sweden as well as a literature review.

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Keywords: Smart maintenance; Maintenance 4.0; Industry 4.0; Socio-technical systems; Transformation system

1. Introduction

The subject of Industry 4.0 is described in many ways, such as a combination of Information Technology (IT), manufacturing processes and the Internet [1], digital transformation, the fourth industrial revolution and smart

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factories [2]. Bajic et al. [3] state that the aim of Industry 4.0 is to integrate the physical world of production processes, such as machinery and sensors, with the cyber world, such as advanced software that can be used for prediction, control and maintenance. Moreover, Liu and Xu [4] state that Industry 4.0 deals with Information and Communication Technologies (ICT), intelligent factories and the development of Internet and embedded system technologies. Furthermore, in line with Vaidya et al. [5], Industry 4.0 is presented through nine technologies: 1) Industrial Internet of Things (IIoT), 2) Big Data and Analytics, 3) Augmented Reality (AR), 4) Simulation, 5) Autonomous Robots, 6) Additive Manufacturing (AM), 7) Cyber Security, 8) Cloud Computing and 9) System Integration. These have resulted in many new devices and connectivity, that may possibly drive manufacturing companies to improve the performance of their processes and increase their production efficiency [6].

Smart maintenance has become a popular research topic, focusing on, for instance, how the technologies can be used for condition monitoring of equipment, remote services, modelling wear of components, calculating Remaining Useful Life (RUL) and prediction of failure [7]. To a lesser extent the research considers humans and their interactions with the technologies [7]. One problem is that the challenges of implementing smart maintenance technologies, presented in previous research on smart maintenance, are commonly not analyzed in a structured way according to any type of socio-technical system. Reviews by Bokrantz et al. [8] and Huang et al. [9], show that many researchers focus on technologies for condition monitoring of equipment, remote supervision and services, failure prediction and calculation of RUL, but many industrial companies still utilize reactive maintenance and are experiencing too much downtime [10]. A study performed by Giliyana et al. [11], shows that out of eleven large manufacturing companies, three had not implemented any smart maintenance technologies and one other company had only implemented a smaller pilot project. Another study, by Giliyana et al. [12, 13], based on empirical data from 15 Small and Medium-Sized Enterprises (SMEs) within the manufacturing industry, shows that no smart maintenance technology had been implemented in the case companies. The studies by Giliyana et al., show that knowing what type of data to collect and what to monitor are two common challenges. Knowledge-related challenges are also pointed out by Masood and Sonntag [13] as common when implementing new technologies. Another study, performed by Bengtsson [14], considering implementation of techniques for Condition Based Maintenance (CBM), pointed out that it is not only technology that should be considered in the implementation process, but also humans and organizations to achieve success. Regarding humans, a study by Salonen [15], found that 50-63% of the breakdowns were caused by human error. Furthermore, according to Salonen [16], it is not commonly discussed how smart maintenance technologies can be utilized in order to reduce the human errors in operation or in maintenance.

The aim of this paper is to study the challenges and enablers related to humans, organizations and technologies when implementing and using smart maintenance technologies in the manufacturing industry. This paper is based on empirical data from seven large manufacturing companies in Sweden, as well as a literature review, performed to gain relevant knowledge of the Industry 4.0 technologies, AI, CPS, and smart maintenance and particularly challenges and enablers when implementing and using the technologies.

2. Smart maintenance technologies

In the subject of Industry 4.0, various maintenance concepts and tools have been discussed such as: eMaintenance [17], Smart Maintenance, Self-Maintenance [18], Predictive Maintenance and Prescriptive Maintenance, as well as Maintenance 4.0. According to Silvestri et al. [19], Lee et al. [20] and Al-Najjar et al. [21], smart maintenance technologies are developed through the nine technologies of Industry 4.0, AI and CPS. Using these types of technologies to improve production maintenance is also noticed by Bengtsson and Lundström [22], who show the importance of combining the new technologies with basic maintenance concepts. Additionally, Silvestri et al. [19] and Forcina et al. [23] state that each of the nine technologies may have a role in the development of smart maintenance technologies. Moreover, an overview of the implementation of maintenance 4.0 technologies is presented by Forcina et al. [23], consisting of key factors, such as CPSs, Big Data Analytics, Cloud Databases, Simulations, AR and Autonomous Robots. The critical aspects presented by Forcina et al. [23], are accuracy of simulations, reliability of health indexes, reliability of AI and potential lack of complete wireless connections. Furthermore, Forcina et al. [23] found that IIoT and Cloud Computing are enablers not only in Industry 4.0, but also in Maintenance 4.0.

Moreover, IIoT is used for connectivity to collect maintenance data through different types of sensors and communication protocols, such as Open Platform Communications-Unified Architecture (OPC-UA) and Message

Queuing Telemetry Transport (MQTT), which are two common protocols used in industrial settings [24]. Connectivity and data collection using different types of sensors and communication protocols allow the development of the technology Big Data and Analytics, where machine learning models can be used for the analytics and data-driven maintenance decision-making [19, 20, 25, 26]. One example is using unsupervised machine learning models, such as Isolation Forest, in order to detect anomalies in unlabeled maintenance data [27]. Additionally, IIoT, Big Data and Analytics and machine learning models are applicable in various fields, such as maintenance trend analysis, monitoring, inspection and control, fault diagnosis and fault classification [19].

For further improvement of production maintenance, Simulation can be used to predict the behavior of a production system and thereby plan maintenance activities based on the data from the simulation models [28]. According to Goodall et al. [28], Simulation can be used to predict the performance of manufacturing systems and supporting maintenance decisions. Additionally, in line with Goodall et al. [28], correctly used Simulation models may reduce cost and time of maintenance, through adapting to changes or the level of available information. One example of Simulation in the context of predictive maintenance by using historical databases is presented in Susto et al. [29].

Utilizing Cloud Computing, the maintenance data can be shared with multiple departments, such as the maintenance and production departments. Regarding the production department, Cloud Computing will possibly be helpful to share information related to Autonomous Maintenance to the operators when performing these types of activities, such as cleaning and lubrication. In addition, a cloud-based Computerized Maintenance Management System (CMMS), can be accessed by different users, such as maintenance engineers, maintenance managers, mechanics and electricians, using different types of client media, such as laptops and smartphones [30].

AR plays an important role in the development of smart maintenance technologies and the improvement of production maintenance, offering possibilities of step-by-step guidance for diagnostics and training [31]. The benefits of AR for Preventive Maintenance include its ability to provide maintenance instructions and checklists for maintenance employees [32]. For Corrective Maintenance, AR can be used for remote assistance to the maintenance employees as well as maintenance instructions [32].

According to Chong et al. [31], 3D-CAD can be used to obtain knowledge about the equipment, and AM to print spare parts for older machines [11]. According to Chong et al. [31], AM can be used to generate 3D-printed prototypes that are useful to generate knowledge about production techniques and maintenance tasks in easier and faster ways.

When working with Industry 4.0 technologies, many different types of systems, sensors and software might be used, and it is essential that these can communicate with each other to make more efficient decisions. Regarding the technology System Integration, through different types of Application Programming Interfaces (APIs) and communication protocols, different systems, sensors, and software can be integrated with each other to make more efficient decisions. One example could be the integration of a CMMS with a vibration measurement system, which may result in the possibility that work orders can be generated automatically in the CMMS based on vibration anomalies found by, for example machine learning models [33]. Moreover, AR systems may be integrated to generate maintenance instructions when work orders are automatically generated in CMMS [33].

2.1. Challenges and enablers

Many challenges are presented in previous research. Two most common challenges are training of the workforce and lack of knowledge [13]. Some other challenges, as mentioned in Masood and Sonntag [13], are 1) Support from experts, 2) Time to work with the new technologies, 3) Awareness of a wide number of technologies and 4) Large investments. Furthermore, many Industry 4.0 implementation challenges are mentioned in Bajic et al. [3], such as 1) The technologies' maturity, 2) Awareness of what kinds of Industry 4.0 technology exist, 3) Large investments and uncertain returns, 4) Poor data quality, 5) Too large dataset to manage and store, 6) Competence, 7) Lack of employees with a clear vision to Industry 4.0 technologies implementation, 8) Resistance to knowledge upgrades, 9) Cyber Security and protection, 10) Low level of trust with second parties, 11) Security challenges related to connectivity protocols, 12) Lack of manufacturing System Integration, 13) Lack of internet connectivity, 14) The inability to extract knowledge from data and 15) Lack of strategy. Further, many challenges in implementing smart maintenance technologies are presented by Giliyana et al. [12] and Giliyana et al. [11], such as 1) Start-up cost, 2) Cyber Security, 3) Change management, 4) Older machines, 5) Resources and competence, 6) Know what to monitor and know what data to collect, 7) Competence and experience in senior position, 8) The maturity of the technology and 9) To make

the technologies work and make everyone understand and work after them. Some enablers, as presented in Giliyana [34], are, working in a cross-functional team, good communication between departments, education and training, use pilot projects, implement gradually, give responsibility to motivate employees and delegate the right task to the right person.

3. The interplay between humans, technologies and organizations

Different types of systems to improve the interactions between humans and technologies are presented in previous research. Their common purpose is how humans and technologies co-exist and interact [7].

In Socio-technical system, presented by Davis et al. [35], the interplay between goal, people, processes/procedures, building/infrastructure, technology and culture, is in focus, and affected by financial/economic circumstances, regulatory frameworks and stakeholders [35].

Related to smart maintenance technologies, Silvestri et al. [19] have elaborated on the Operator 4.0 concepts and mention that technological and industrial development is also influenced by how humans will manage and use new technologies. One example, mentioned in Silvestri et al. [19], is that Big Data and Analytics is an important driver for economical innovation, but a lack of skilled operators decelerate this innovation. Operator 4.0 is also presented by Forcina et al. [23], who state that when using the nine technologies of Industry 4.0, new skills are demanded of users, such as interaction with Autonomous Robots, AM and AR.

Cyber-physical social system, which is presented by Ansari et al. [36], tends to integrate computation with physical processes as well as human and social characteristics.

Furthermore, Bokrantz et al. [8] have presented smart maintenance through four dimensions: 1) Data-driven decision-making, making decisions based on data, 2) Human capital resources, the competence development of maintenance employees, such as analytical skills and ICT skills, 3) Internal integration, the integration of the maintenance organization with other internal organizations. The last dimension is, 4) External integration, integrating maintenance with external organizations, such as machine suppliers.

Moreover, Säfsten and Bellgran [37] state that the industrial processes can be seen as a system involving a combination of different elements, such as Technology, People and Processes.

In this research study we have been inspired by the Transformation System, presented by Hubka and Eder [38]. This system consists of Human System (Hu), Technical System (TS) and the Active Environment (AEnv), which affect the Transformation Process (TP). See Fig. 1, which visualizes that not only the TS, but also Hu and AEnv affect the TP and the quality of the output Od^2. This system is also used by Bengtsson [14], in supporting the implementation of CBM in the manufacturing industry, which is of interest for this paper, since according to Al-Najjar et al. [21], CBM is expected to play a dominant role in the development of smart maintenance technologies.

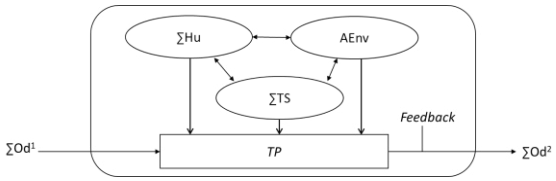

Fig. 1. Transformation System [38].

4. Methodology

This paper is based on a case study [39]. Semi-structured interviews are used to collect empirical data, [40] which is analyzed through a process for qualitative data analysis [41, 42]. In addition, a literature review is conducted to gain relevant knowledge of the studied area.

4.1. Data collection

We collected the empirical data in 2023, using semi-structured interviews with respondents from seven large manufacturing companies in Sweden, which are renowned being at the forefront of technological development. Two are classified as lighthouse factories within the Swedish industry, E and G, see Table 1. To increase the validity of the empirical data, we made certain that the chosen respondents had experience in and worked with maintenance development.

The semi-structured interview questions were (shortened): (1) How do you see the term "Smart Maintenance"?, (2) How do you see the term "Smart Maintenance Technologies"?, (3) What types of technologies have been implemented or tested in your maintenance processes, and in what context?, (4) Was a process followed during the implementation of smart maintenance technologies?, (5) Would a specific process be needed?, (6) What are the challenges with the technologies in your maintenance processes? When implementing., (7) What are the challenges with the technologies in your maintenance processes? When using., and (8) What benefits, if any, do the technologies add to your maintenance processes?

The unit of analysis in this paper is the challenges and enablers related to humans, organizations and technologies, in the context of the implementation and use of smart maintenance technologies in the manufacturing industry. Therefore, this paper's empirical inquiry is primarily based on the interview questions that is regarding the smart maintenance technologies that have been implemented or tested, as well as any challenges encountered during their implementation and use.

To gain relevant knowledge of the Industry 4.0 technologies, AI, CPS, and smart maintenance and particularly challenges and enablers when implementing and using the technologies, a literature review has been performed. The selected literature was mainly based on scientific papers. We have used Google Scholar as a main search engine. The search terms were "smart maintenance", "smart maintenance and implementation", "smart maintenance and challenges", "smart maintenance and enablers", "predictive maintenance", "maintenance 4.0", "Industry 4.0", "Industry 4.0 technologies", "Industry 4.0 and challenges", "Industry 4.0 and enablers", "Industry 4.0 and implementation", "socio-technical system" and "Industry 4.0 and socio-technical systems".

Table 1. Case companies.

	Site empl.	Maint. depart. size	Type	Position	Date	Dura. (min)
A	1700	230	Automotive industry	Maintenance manager	03-16	49
B	600	50	Automotive industry	Two maintenance eng.	03-16	24
C	10000	1000	Automotive industry	Maintenance analyst	03-28	28
D	1000	70	Automotive industry	Maintenance engineer	03-30	35
E	2000	100	Manuf. of bearings, seals, and lubr. systems	Maintenance manager	04-27	32
F	5000	400	Automotive industry	Maintenance engineer	05-22	39
G	250	21	Manuf. of tools and machining solutions	Maintenance manager	05-23	43

4.2. Data analysis

To analyze the data, primarily concerning challenges when implementing and using smart maintenance technologies, we have been inspired by a qualitative data analysis process, presented by Miles et al. [41] and Saldaña [42]. First, we transcribed the recordings from the semi-structured interviews. Second, we condensed the data based on the interview questions, and we coded the data according to the first and second cycle coding. In the first cycle coding, which is a way to initially summarize segments of data, we coded challenges in implementing and using smart maintenance technologies in NVivo, a software for qualitative data analysis. In total, we found nineteen codes that were discussed by the respondents. In the second cycle coding, pattern coding, which is a way of grouping codes into

a smaller number of categories, themes, or concepts, we grouped the codes into six categories based on patterns that we could find [41, 42]. Lastly, based on patterns, we grouped the categories into three themes, inspired by the Transformation System presented by [38]. The categories will be elaborated on below in Section four. Later, in Section five, we pair the categories of challenges with theoretically grounded enablers as recommendations to help overcome them.

5. Empirical findings and analysis

The empirical findings show that all case companies have implemented some type of smart maintenance technologies, such as mobile applications, sensors, automatic vibrations sensors, dashboards, AI algorithms, IoT platforms and visualizations software. Additionally, the empirical findings show that all case companies face many challenges when implementing and using smart maintenance technologies. As mentioned above, the challenges are coded, categorized, and thematized, inspired by the Transformation System [38]. See Fig. 2.

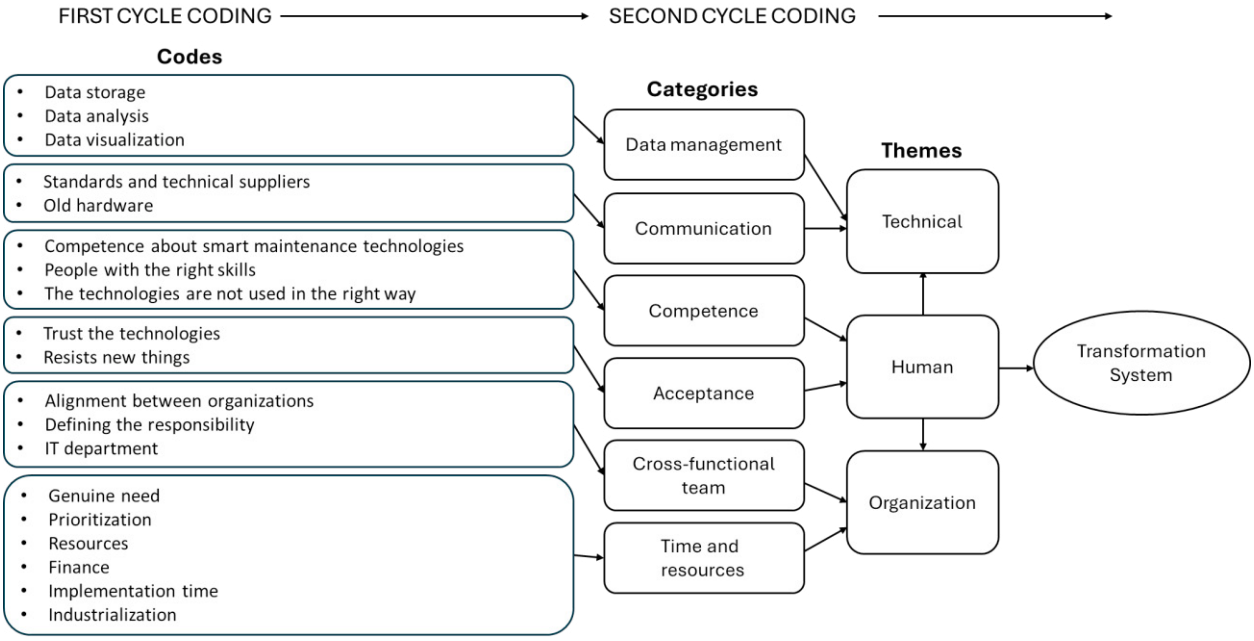

Fig. 2. An overview of the challenges when implementing and using smart maintenance technologies.

Data management: This category covers the challenges related to data storage, such as where to store the data and how to store the data. Furthermore, this category covers the challenges related to data analysis and visualization, such as how to analyze the data and how the data should be visualized in a simple and efficient way.

Communication: Too many communication standard protocols and technical suppliers to manage and to adhere to. Moreover, this category covers challenges related to old hardware, such as old machines, that are not compatible with the new technologies.

Competence: Competence about smart maintenance technologies, such as difficulty to use the technologies, difficulty to select proper signals from machines' PLC, difficulty to use and analyze the data, finding correlations and setting limits and learning what is acceptable and what is outside of the tolerance. Moreover, this category includes challenges related to finding people with the correct skills. To ensure that the technologies are used in the right way is another challenge in this category, since one common mistake is, for instance to replace components based on the output from a technology without doing root cause analysis which may cause the failure to happen again repeatedly.

Acceptance: Another challenges is to put trust into the technology and not resisting new things, such as some technologies are quickly accepted while other are accepted more slowly and that the individuals need a journey of

change. Moreover, this category covers challenges related to acceptance from the production manager since one risk is that the manager does not accept the machine to be shut down to install sensors.

Cross-functional team: Alignment between organizations and defining responsibilities, since smart maintenance technologies are characterized by cross-border technologies and different departments are involved in the implementation process, e.g. maintenance, IT, and production. Furthermore, this category presents challenges related to getting support from IT department.

Time and resources: There must be a genuine need for business. If there is no genuine need from the business, the likelihood of it getting adopted reduces. With different implementation ideas coming from different departments, such as maintenance and production, the challenge is to find a suitable prioritization and manage all the ideas that come in. Other challenges in this category are, lack of resources, to convince different organizations that the implementation is worth the investment since a lot is linked to the fact a quick return is demanded, to find time to work with these technologies and to industrialize the solutions.

6. Enablers

To overcome challenges related to **Data management**, Bajic et al. [3] suggest to train and create cross-functional teams within the company, to teach a new generation of students and researchers about current and future industry trends regarding Big Data and Analytics, implement pilot projects for testing developed analytical models, and to implement data storage with multiple decentralized locations to store data. Regarding SMEs, Bajic et al. [3] suggest to establish collaboration between multiple SMEs to divide the implementation cost and collaboration between SMEs and academia to apply for fundings for international implementation projects. Furthermore, Lee et al. [43] have mentioned four enablers in order to overcome the challenges related to data analysis using AI, 1) Understanding the problem and focus on the power of industrial AI into solving it, 2) Understanding the system so that right data with the right quality can be collected, 3) Understanding the physical meanings of the parameters and how they are associated with the physical characteristics of a system or process and 4) Understanding how these parameters vary from machine to machine.

Regarding **Communication**, to overcome challenges related to old hardware, external sensors that are independent on the machines' Programmable Logic Controller (PLC) can be used to collect maintenance data, such as vibration and temperature. Two common communication standards are OPC UA and MQTT [24]. One suggestion is to adhere to one standard and communicate it to the technical suppliers. Adhering to one standard will make it possible to send data between different systems and make decisions based on data from different systems from different brands [34].

Bajic et al. [3] suggest many opportunities to overcome challenges related to **Competence**, such as, providing employees with training on Industry 4.0 that shows the benefits to the company and employees, motivating employees to commit to Industry 4.0 implementation by presenting the advantages of Industry 4.0 to the company management and employees and train teams within the company in Industry 4.0 technologies.

Lundgren et al. [44] make following recommendations in relation to overcoming the challenges related to **Acceptance**, such as, formulate and communicate a clear vision, clarify how concept, such as smart maintenance contribute to the vision and strategy, take help from externals companies to inspire and resolve old patterns, involve employees in workshops since they usually have many ideas for improvements and create an innovative environment to welcome any implementation suggestion. Furthermore, Bajic et al. [3] suggest developing user-friendly devices to motivate employees to transfer from old to new technologies.

Marquez [45] and Salonen [46] present six steps for formulation of the maintenance strategy. We see the two first steps as opportunities to overcome the challenges related to **Cross-functional team**, 1) Identify that strategic goal for all stakeholders and 2) Identify the strategic goal for the maintenance department. When implementing smart maintenance technologies, different departments are involved in the implementation process. Therefore, identifying strategic goals for each department and the maintenance department will support overcoming the challenge related to defining responsibility. Further, good communication between departments and give clear responsibility in order to motivate employees, are two enablers mentioned by Giliyana [34].

For **Time and resources**, Lundgren et al. [44] recommend ensuring commitment from top management to gain necessary resources, prioritization between improvement ideas and to make sure that employees can formally report time spent on different improvement ideas to be sure that the employees are doing right things. Furthermore, Giliyana

[34] suggests demonstrating the benefits of smart maintenance to get management approval and gain resources. Pilot projects and testbeds for smart maintenance technologies could be some options.

Table 2. Summary of the recommendations.

Category	How to overcome the challenges within each category
Data management	• Train and create cross-functional teams within the company. • Teach a new generation of students and researchers about current and future industry trends. • Pilot projects for testing developed analytical models. • Implement data storage with multiple decentralized locations. • Establish collaboration between multiple SMEs to divide the implementation cost and collaboration between SMEs and academia to apply fundings for international implementation projects. • Understanding the problem and focusing on the power of industrial AI into solving it. • Understanding the system so that the right data with the right quality can be collected. • Focus on having domain knowledge before deciding to use AI models.
Communication	• Use external sensors that are independent of the machines' PLC and can be used to collect maintenance data, such as vibration and temperature. • Adhere to one standard and communicate it to the technical suppliers.
Competence	• Provide employees with Industry 4.0 training that shows the benefits to the company and employees. • Motivate employees to commit to Industry 4.0 implementation by presenting the advantages of Industry 4.0 for the company and employees. • Train teams within the company in Industry 4.0 technologies.
Acceptance	• Formulate and communicate a clear vision. • Clarify how concepts, such as smart maintenance contribute to the vision and strategy. • Take help from external companies to inspire and resolve old patterns. • Involve employees in workshops since they usually have many ideas for improvements. • Welcoming any implementation ideas by creating an innovative environment for that. • Develop user-friendly devices to motivate employees to transfer from old to new technologies.
Cross-functional team	• Identify strategic goals for all departments. • Identify strategic goals for the maintenance department. • Focus on having good communication between departments. • Give clear responsibility to motivate employees.
Time and resources	• Ensure commitment from top management to gain necessary resources. • Prioritization between improvement ideas. • Ensure that employees can formally report time spent on different implementation ideas to be sure that they are doing the right things. • Demonstrate the benefits of smart maintenance to get management approval and gain resources.

7. Conclusions

The aim of this paper is to study the challenges and enablers related to humans, organizations and technologies when implementing and using smart maintenance technologies in the manufacturing industry. The empirical findings have shown that all seven case companies in this study have implemented some type of smart maintenance technologies, as such, the respondents could be considered qualified to elaborate on issues of implementing and using smart maintenance technologies. The empirical findings also show that all case companies face many challenges when

implementing and using smart maintenance technologies. Previous research on smart maintenance is to a large extent focusing on elaborating how the Industry 4.0 technologies, as well as AI and CPS, can be used for condition monitoring of equipment, remote services, modelling wear of component, calculating RUL and prediction of failure [7], but humans and their interactions with the technologies are not considered to a high extent. In this paper, we have, through empirical evidence, visualized that to achieve success, not only the technology should be considered during the implementation, but also humans using the technologies and support from organizations, which is also stated by [7], [9-11] and [16]. The challenges we identified are coded, categorized and thematized, as Fig. 2 shows. To help overcome these challenges they have been paired with theoretically grounded enablers. One suggestion for companies either embarking on an implementation of smart maintenance technologies or that are in a use-phase is to study Fig. 2 and Table 2, as guidelines. Implementing and using smart maintenance technologies is not to be seen as a pure technological implementation but rather through lenses of the interplay between humans, technologies and organizations, inspired by a Transformation System presented by Hubka and Eder [38].

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