Received 3 June 2020
Revised 10 September 2020
9 December 2020
28 February 2021
Accepted 30 March 2021

A strategy development process for Smart Maintenance implementation

Camilla Lundgren, Jon Bokrantz and Anders Skoogh
Department of Materials and Industrial Science, Chalmers University of Technology, Gothenburg, Sweden

Abstract

Purpose – Technological advancements are reshaping the manufacturing industry toward digitalized manufacturing. Despite the importance of top-class maintenance in such systems, many industrial companies lack a clear strategy for maintenance in digitalized manufacturing. The purpose of this paper is to facilitate the implementation of maintenance in digitalized manufacturing by proposing a strategy development process for the Smart Maintenance concept.

Design/methodology/approach – This study is designed as a multiple-case study, where the strategy development in three industrial cases is analyzed. Several methods were used to collect data on the case companies' development of smart maintenance strategies. The data were analyzed with an inductive approach.

Findings – A process of strategy development for smart maintenance is proposed, including six steps: benchmarking, setting clear goals, setting strategic priority, planning key activities, elevating implementation and follow-up.

Practical implications – The proposed process provides industry practitioners with a step-by-step guide for the development of a clear smart maintenance strategy, based on the current state of their maintenance organization. This creates employee engagement and is a new way of developing maintenance strategies.

Originality/value – Maintenance strategies are traditionally regarded as a selection of corrective/reactive and preventive maintenance actions using a top-down approach. By contrast, the proposed process is starting from the current state of the maintenance organization and allows a mixture of top-down and bottom-up approaches, supporting organizational development. This is a rare perspective of maintenance strategies and will make maintenance organizations ready for the demands of digitalized manufacturing.

Keywords Maintenance, Strategy, Manufacturing industry, Benchmarking, Case studies

Paper type Research paper

1. Introduction

There has been a shift in our society, whereby innovations and advancements in technology have changed our dependency on technology. The new technologies are creating opportunities to reshape the manufacturing industry toward digitalized and interconnected manufacturing. Digitalized manufacturing, e.g. the German initiative, "Industrie 4.0" (Xu *et al.*, 2018), refers to manufacturing in which the physical and virtual worlds are connected. The production systems rely on computer science and advanced manufacturing technology (Kagermann *et al.*, 2013; Xu *et al.*, 2018), including substantially higher levels of automation with decentralized systems

The authors would like to thank SMASh, a research project financed by VINNOVA and Production 2030. The authors especially thank the case companies for commitment and collaboration. The authors also would like to thank all individuals who contributed to this research. This work was financed by VINNOVA [grant number 2017-01652]. This work has been performed within Production Area of Advance at Chalmers. The support is greatly appreciated.

working and acting autonomously. Avoiding unexpected stoppages and disruptions has become crucial to such systems. Nevertheless, too many companies are experiencing excess failure-mediated downtime, with overall equipment effectiveness (OEE) at around 50% (Ylipää *et al.*, 2017), not something that is associated with digitalized manufacturing. To make maintenance organizations ready for the requirements of digitalized manufacturing, companies need to develop maintenance strategies accordingly.

A strategy has long been viewed as a plan by top-level management, which, in turn, determines what happens at an operational level (Porter, 1996). From a maintenance perspective, a maintenance strategy is commonly considered as a selection of corrective/reactive, preventive and condition-based maintenance (Al-Najjar and Alsyouf, 2003; Bevilacqua and Braglia, 2000; Gutschi *et al.*, 2019; Ilangkumaran and Kumanan, 2009; Shyjith *et al.*, 2008; Tan *et al.*, 2011; Wang *et al.*, 2007). This selection would be more appropriately described as a maintenance plan to handle equipment failure, which is not a way to support the implementation of maintenance in digitalized manufacturing. Previous research has highlighted that a maintenance strategy should include organizational aspects, such as knowledge and skill development (Tsang, 1998), culture and organizational structure (Bengtsson and Salonen, 2009). This is particularly important when developing strategies for maintenance in digitalized manufacturing (Bokrantz *et al.*, 2020b). However, there is limited research about the work procedure for developing strategies for the implementation of maintenance in digitalized manufacturing (Silvestri *et al.*, 2020). There is a need to develop entire maintenance organizations and formulate strategies that can be adjusted to their current state and their desirable future state. Therefore, this study bases the strategy development on a conceptually clear and empirically measurable concept for maintenance in digitalized manufacturing: smart maintenance (Bokrantz *et al.*, 2020c).

This paper proposes a clear, step-by-step process for strategy development, aiming to facilitate the implementation of maintenance in digitalized manufacturing. The proposed process contributes to a new way of perceiving and developing maintenance strategies. This new perspective on maintenance strategies allows for continuous development of the maintenance organization to make it ready for the demands of digitalized manufacturing. The paper is structured as followed: firstly, we present a theoretical background (Section 2), followed by an explanation of our research methodology (Section 3). Next, we present our empirical findings by describing each case (Sections 4.1–4.3). We then compare the cases through a cross-case analysis (Section 4.4), followed by theoretical interpretations where the cases are related to the theoretical framework (Section 4.5). Based on the cases and our theoretical interpretations, we propose a process for smart maintenance strategy development (Section 5). Finally, the study is summarized in the discussion and conclusion sections (Sections 6 and 7), including theoretical and practical implications, limitations of the study and proposed future research.

2. Theoretical background

2.1 Digitalization of the manufacturing industry

Many industrial companies are currently undergoing a reshaping toward digitalization, facilitated by innovation and advancement in technology. This reshape was conceptualized in the German initiative "Industrie 4.0" in 2011 and has since then evolved in what it comprises and how it is perceived (Culot *et al.*, 2020). There are several definitions and descriptions of Industry 4.0 (Culot *et al.*, 2020; Nosalska *et al.*, 2020; Ghobakhloo, 2018), and similar concepts are used as alternative expressions for the same phenomena. For example, "smart manufacturing," "digital transformation," "fourth industrial revolution" and "smart factories." There are, however, some commonalities in different definitions of Industry 4.0

and similar concepts, which seem to be important characteristics. Industry 4.0 is based on computer science and advanced manufacturing technology (Kagermann *et al.*, 2013; Xu *et al.*, 2018), with key technologies such as big data, cyber-physical systems (CPS), internet of things (IoT), cloud computing and three-dimensional (3D) printing (Culot *et al.*, 2020; Lu 2017). It is not only about technology within manufacturing, but also about changing value chains, business models, as well as personalized and smart products (Nosalska *et al.*, 2020). In this paper, we will use "digitalized manufacturing" to refer to the concept of digitalization of the manufacturing industry.

2.2 Maintenance in digitalized manufacturing

Maintenance organizations need to develop to keep up with the advancements of digitalized manufacturing (Akkermans *et al.*, 2016; Bokrantz *et al.*, 2020c). In organizational changes, it is necessary to specify exactly what is intended to be accomplished to get support from the whole organization (Mento *et al.*, 2002). Thereby, it becomes important to specify the desirable future state, as well as the current state of the maintenance organization, to exactly specify what is intended to be accomplished in developing maintenance in digitalized manufacturing.

There is an abundance of concepts for maintenance in digitalized manufacturing. Maintenance practices have long followed a reactive approach but have during the past decades shown the development of more proactive approaches, considering the relevance of failure avoidance. Technologies such as big data, CPS, IoT and cloud computing (Lu, 2017) have stimulated advances within the maintenance field and have promoted interest in technologies for condition monitoring of equipment, remote services, modeling wear of components, calculating remaining useful life and prediction of failures. Examples include Galar *et al.* (2015), Grubic and Peppard (2016), Lee *et al.* (2015), Li *et al.* (2017) and Roy *et al.* (2016). One frequently mentioned term is predictive maintenance. The interest in predictive maintenance has increased in both industry and academia, aiming to foresee breakdowns by detecting anomalies in data that are likely to be early signs of failure (Compare *et al.*, 2020; Selcuk, 2017). The reshaping of maintenance practices has been described in empirical research (Akkermans *et al.*, 2016; Bokrantz *et al.*, 2017) and various maintenance concepts for digitalized manufacturing have been proposed. Some examples include predictive maintenance (Carnero, 2005), e-maintenance (Lee *et al.*, 2006; Muller *et al.*, 2008), prognostics and health management (Lee *et al.*, 2014), Maintenance 4.0 (Kumar and Galar, 2018) and smart maintenance (Munzinger *et al.*, 2009; Bokrantz *et al.*, 2020c). Reviews by Bokrantz *et al.* (2020c) and Huang *et al.* (2020) have found that the suggested concepts are not clearly defined. There is an overlap in these concepts, with a varied use of terminology, causing a lack of concept clarity. This lack of concept clarity makes it difficult to specify the desirable future state.

To determine the current state of maintenance organizations, numerous maturity models are available in the literature. Maturity models are popular in both academic and industrial environments and have long been used to assess current maintenance practices (see, e.g. Antil, 1991; Chemweno *et al.*, 2015; Mehairjan *et al.*, 2016; Oliveira and Lopes, 2019). Maturity models have also been developed to, more specifically, assess maintenance organizations in the digitalized context. Macchi *et al.* (2017) used a maturity assessment method (Macchi and Fumagalli, 2013) to assess the advancement of maintenance management toward smart maintenance, including assessment items of technological, organizational and managerial capabilities. Nemeth *et al.* (2019) present a maturity model including data quality, information quality, knowledge quality and maintenance quality as assessment items. As a final example, Poór *et al.* (2019) propose a maturity model based on elements of Industry 4.0, with an assessment based on functionality (planning and integration), decision support (data), business process (digitalization and automation), users (motivation) and technologies. Maturity models are easy to use and provide a rather quick assessment of the maintenance function. However, newly developed maturity models are rarely tested for empirical validity

(Becker *et al.*, 2010). This makes it difficult to exactly determine the current state of the maintenance organization.

There is, however, one stream of research that in detail can help in specifying what is intended to be accomplished for maintenance in digitalized manufacturing and determine the current state of the organization: smart maintenance (Bokrantz *et al.*, 2020c). It is a concept for maintenance in digitalized manufacturing that is clearly defined as "an organizational design for managing maintenance of manufacturing plants in environments with pervasive digital technologies" (Bokrantz *et al.*, 2020c); it can be empirically measured in a valid and reliable manner using a psychometric measurement instrument (Bokrantz *et al.*, 2020a). Therefore, to ground the development of maintenance strategies in existing theory and practice, smart maintenance was chosen as the focal concept in this study. The concept of smart maintenance consists of four underlying dimensions: (1) data-driven decision-making (DDD), (2) human capital resource (HCR), (3) internal integration (INI) and (4) external integration (EXI) (Bokrantz *et al.*, 2020c). Please see Figure 1.

The first dimension, DDD, is defined as "the degree to which decisions are based on data" (Bokrantz *et al.*, 2020c). It represents the extent to which maintenance decisions are based on collected, quality ensured data. The second dimension, HCR, is defined as a "unit capacity based on individual knowledge, skills, abilities and other characteristics (KSAO) that are accessible for unit-relevant performance" (Bokrantz *et al.*, 2020c). This includes generic skills (such as communication) and specific skills (such as data analytics). The third dimension, INI, is defined as "the degree to which the maintenance function is a part of a unified, intra-organizational whole" (Bokrantz *et al.*, 2020c). This includes cross-functional collaboration and closer synchronization between the maintenance function and the rest of the organization. The fourth and final dimension, EXI, is defined as "the degree to which the maintenance function is a part of a unified, inter-organizational whole" (Bokrantz *et al.*, 2020c). EXI means having close contact with external parties (outside the plant through, say, networks, and strategic partnerships).

A measurement instrument has been developed and empirically validated (Bokrantz *et al.*, 2020a) to measure each of the four dimensions of smart maintenance. It allows assessment, benchmarking and longitudinal evaluation of smart maintenance within and across

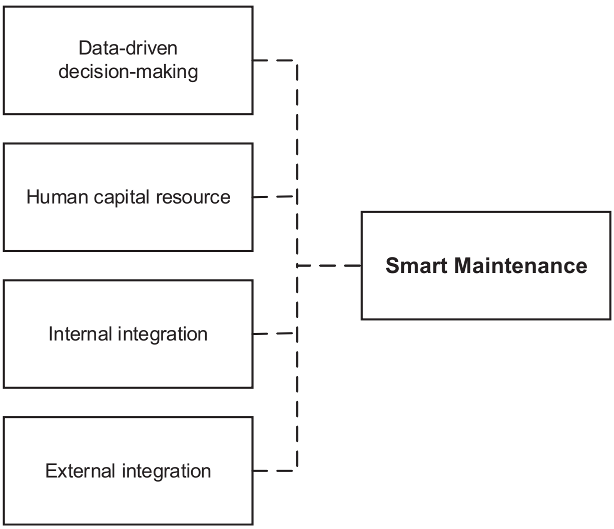


Figure 1.
The four underlying dimensions of smart maintenance

organizations. The measurement instrument consists of a set of validated questions addressing each of the four dimensions of smart maintenance. It can be used as a self-administered questionnaire, whereby the results from each of the dimensions may be further compared to an industry average (based on the set of 59 plants used in Bokrantz *et al.*, 2020a) for benchmarking smart maintenance across organizations. The assessment provides industry practitioners with an understanding of smart maintenance within their organization. Further, each of the questions in the assessment can be used to identify potential improvements. Once potential improvements have been identified, companies can start developing their smart maintenance strategy.

2.3 Strategy development and roadmapping

A strategy has long been viewed as a plan, to create "a unique and valuable position, involving a different set of activities" (Porter, 1996). There are two major perspectives on strategy: strategy-as-plan and strategy-as-practice. Strategy-as-plan indicates strategy as a plan, including desirable company goals, with actions and resource allocation to reach those goals (Mintzberg *et al.*, 2005). This is typically achieved via a top-down approach, with the strategy formulated by top management and then implemented at operational levels (Porter, 1996). By contrast, strategy-as-practice is a mixture of top-down and bottom-up approaches (Mintzberg and Waters, 1985), with middle managers and operational employees involved (albeit not formally) in strategy formulation (Jarzabkowski *et al.*, 2007). The strategy is dynamic, reflecting what is done in practice and may, thus, gradually evolve (Jarzabkowski *et al.*, 2007; Whittington, 2004). By contrast, maintenance strategies traditionally focus on the mathematical evaluations to create plans for equipment repairs (Al-Najjar and Alsyouf, 2003; Bevilacqua and Braglia, 2000; Gutschi *et al.*, 2019; Ilangkumaran and Kumanan, 2009; Shyjith *et al.*, 2008; Tan *et al.*, 2011; Wang *et al.*, 2007). There is limited guidance from research on how to support organizational development for maintenance in digitalized manufacturing (Silvestri *et al.*, 2020).

A strategy must be linked to the company goals and be developed concerning the internal and external environment to lead to performance (Dangayach and Deshmunk, 2001; Galbraith and Schendel, 1983). For a maintenance strategy, it means considering external factors (such as the production environment and suppliers) and internal factors (such as leadership and processes within the maintenance function). From a smart maintenance perspective, a set of factors facilitates or inhibits implementation; leadership, corporate culture and information technology (IT) security for example (Bokrantz *et al.*, 2020b). To prevent obstructive attitudes from employees during implementation (Salonen and Bengtsson, 2011), employees need to be involved (Veile *et al.*, 2020), and the goals of the maintenance department should be linked, not only to overall company goals but also to employees' individual goals (Klein and Sorra, 1996).

To sustain employee engagement, it is important to conduct follow-up, provide information on progress (Boer and During, 2001) and report any contributions made to the company's overall goals. There are maintenance performance indicators (PIs) available for measuring various aspects, such as financial performance on a company level and job satisfaction on an employee level (Lundgren *et al.*, 2020). Despite this, the use of PIs within maintenance is often limited to technical aspects such as technical availability and the failure rate of equipment (Salonen and Bengtsson, 2011). Changes in strategy require changed PIs (Braz *et al.*, 2011; Simões *et al.*, 2016). For a smart maintenance strategy to succeed, there is a need to update the PIs.

There are various proposed methods of strategy development and formulation, but roadmapping is generally on the increase as a method/tool for visualizing and communicating strategies (Elbanna *et al.*, 2016; Phaal and Muller, 2009; Ghobakhloo, 2018). One such approach is to develop a roadmap in a workshop format. This brings together different stakeholders and competencies, provides dialogue and includes different perspectives on the process (Phaal *et al.*, 2007; Phaal and Muller, 2009). There is no general roadmap that fits all companies that target development in industrial environments dominated by technology, but general approaches to roadmap development have been proposed (Phaal *et al.*, 2007; Ghobakhloo, 2018).

3. Methodology

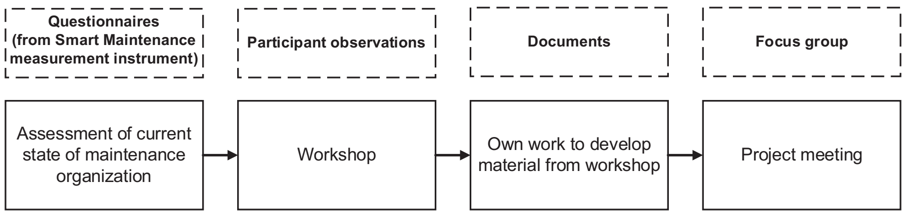
This study was designed as a qualitative, empirical, multiple-case study (Barratt *et al.*, 2011; Yin, 2018) so as to achieve an in-depth understanding of the phenomena of maintenance strategy development. We used purposive sampling (Palys, 2008) to ensure a strategic selection of cases that provides access to information and knowledge about the phenomena under investigation. To mitigate selection bias, we sampled cases that fulfilled three criteria: a dedicated organizational unit for equipment maintenance, dedicated resources to develop smart maintenance strategies and willingness to participate. Three cases were sampled from the Swedish industry: one from discrete manufacturing, one from continuous manufacturing and one from infrastructure and traffic service.

3.1 Data collection

Four different methods of data collection were used: questionnaires for quantitative data, participant observations, documents and focus groups for qualitative data. These methods were used in different phases of the study, to capture the companies' development, for triangulation purposes and to augment the study's validity (Denscombe, 2014; Kawulich, 2005; Yin, 2018). Figure 2 describes the data collection steps of the study.

Firstly, we collected data to determine the current state of the maintenance organization. The maintenance manager from each case was selected to participate in this study. The managers were instructed to invite suitable employees from their organization to participate in the study and thus also be involved in strategy formulation (Jarzabkowski *et al.*, 2007). We used the smart maintenance measurement instrument (Bokrantz *et al.*, 2020a) to collect data on the current state of the maintenance organization within the three case companies. Several people answered the questionnaire, reducing respondent bias (Flynn *et al.*, 2018). Two of the case companies filled out the questionnaire before the workshop (self-administered), while one did it in conjunction with the workshop (further details are given in the case analyses).

In this study, we included all the questions from the four within-factor models reported in Bokrantz *et al.* (2020a), in the questionnaire (8–12 questions per dimension). These questions demonstrate good measurement properties from the empirical pilot study based on 59 plants (Bokrantz *et al.*, 2020a). When using a factor-based measurement instrument in an industrial setting together with practitioners, it is most suitable to compute the factor scores without using sophisticated statistical techniques, to ensure that the results are easy to interpret. Therefore, we computed the score for each dimension by calculating the mean of all raw scores from the questions that load on each factor. To further facilitate interpretation,



Note(s): Four different methods of data collection were used: questionnaire, participant observations, documents and focus group

Figure 2. The four steps in the study were (1) assessment of the current state of the maintenance organization, (2) workshop, (3) own work by the industry practitioners and (4) a project meeting

we created visualizations in the form of density plots. Figure 3 shows an example of a density plot for DDD.

The purple bars represent the frequency of mean values, and the continuous blue line represents the grand mean value, based on the set of 59 plants used in Bokrantz *et al.* (2020a). The scores for each of the case companies in this study are shown by black, dashed lines in the density plots. This visualization allows assessment and benchmarking of the maintenance organization.

Secondly, a workshop was held with each of the case companies. The setup of the workshop was designed by the researchers and further discussed with the case companies and adjusted accordingly. The researcher started the workshop by presenting the results from the measurement instrument. Next, the workshop focused on how to succeed in smart maintenance, by suggesting activities for developing the maintenance organization. An initial roadmap was developed, to visualize the plan of suggested activities. The number of workshop participants ranged from seven to 18, with roles such as maintenance manager, technician, planner and plant manager. Participant observations (Flynn *et al.*, 1990; Kawulich, 2005) were used to collect qualitative data during the workshop, as it allows to collect data on people, processes and cultures. The researcher can, thus, determine interaction, communication and nonverbal expressions of feeling among participants and record their experience (Flynn *et al.*, 1990; Kawluch, 2005). More specifically, the researcher was observer-as-participant (Kawluch, 2005) during the workshops. It allows the researcher to interact with participants without having a major impact on the activities being studied (Adler and Adler, 1994; Kawluch, 2005). The researcher collected field notes during the workshop to reduce retrospective bias. This included a description of the atmosphere, experiences and outcome of the discussions during the workshop, for later analysis.

Thirdly, after the workshop, the companies were asked to continue working on their own with the workshop material for approximately six months. They aimed to develop a roadmap plus a strategy for smart maintenance implementation. The industry practitioners documented their work in a template provided by the researchers. This means that documents were the data source for this phase. The documentation template was used to ensure comparable documents between the cases and thus increase the quality of the cross-case analysis.

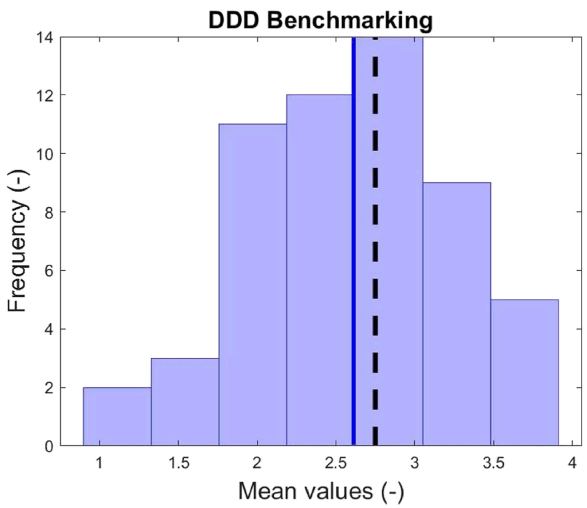


Figure 3.
Example of a density plot for DDD, including the results for the company (black dashed line) and an industrial mean (blue line). A color version of this figure is available online

Fourthly and finally, researchers and representatives from the case companies were gathered for a project meeting. Each company presented its strategy and roadmap, which was followed by a discussion, intended to foster joint learning about the companies' strategy development processes. Focus group discussions (Flynn *et al.*, 1990) between the researchers and participants were used as a data collection method during this project meeting. The discussions focused on a certain level of consensus on key lessons learned, plus the future development of their strategies.

3.2 Data analysis

Once all data had been collected, analysis with an inductive approach began. Three within-case analyses and one cross-case analysis were conducted. The documents from each of the cases (the researcher's field notes from the workshops and documentation from the companies' work) were analyzed with an open coding procedure, inspired by constant comparison (Glaser and Strauss, 1967). For each within-case analysis, the researcher iteratively read the field notes and documentation from the company's work and noted patterns during the workshop, similarities in the documents as well as central issues documented by the case company. The findings from each within-case were summarized in a table. Peer debriefing (Corley and Gioia, 2004) was used to reduce researcher bias and increase the trustworthiness of the analysis. The coding scheme was continuously discussed with research colleagues, which resulted in minor revision and clarification of the codes. Finally, the tables with findings from each case were used in a cross-case analysis to identify similarities and differences between the cases.

The focus group discussion was analyzed to identify key lessons learned across the cases from the companies' work and to cross-check the findings of participant observations (field notes from workshops) and documents (companies' work). The most discussed topics were noted and then cross-checked with the other data sources. Discussions and similarities across all cases were interpreted, to augment the findings. The findings from the cases were then interpreted theoretically, resulting in a proposed process of strategy development for smart maintenance.

4. Empirical findings

This section presents the findings of the study. Firstly, a within-case analysis is given to describe each of the cases. Secondly, the cross-case analysis describes the similarities and differences between the cases. The section ends with theoretical interpretations, where the findings from the cases are related to the theoretical framework.

4.1 Within-case analysis 1

Case 1 is from a discrete manufacturing company. The company chose to conduct a group smart maintenance assessment where the group had to come up with a single joint answer to each question. There were intense discussions, but the participants were able to agree on one answer. Their answers were then used as input to the measurement instrument. The density plot for each smart maintenance dimension appears in Figure 4.

The continuous blue line represents the industrial mean, while the dashed black line represents the mean value from Case 1. The case company scored 2.38 on DDD, 4.36 on HCR, 3.50 on INI and 3 on EXI.

At the beginning of the workshop, the case company suggested many activities related to the DDD dimension of smart maintenance. For example, adding data points, collecting data, specifying requirements for a computerized maintenance management system and deploying the new maintenance system. As the workshop proceeded, activities for the other dimensions

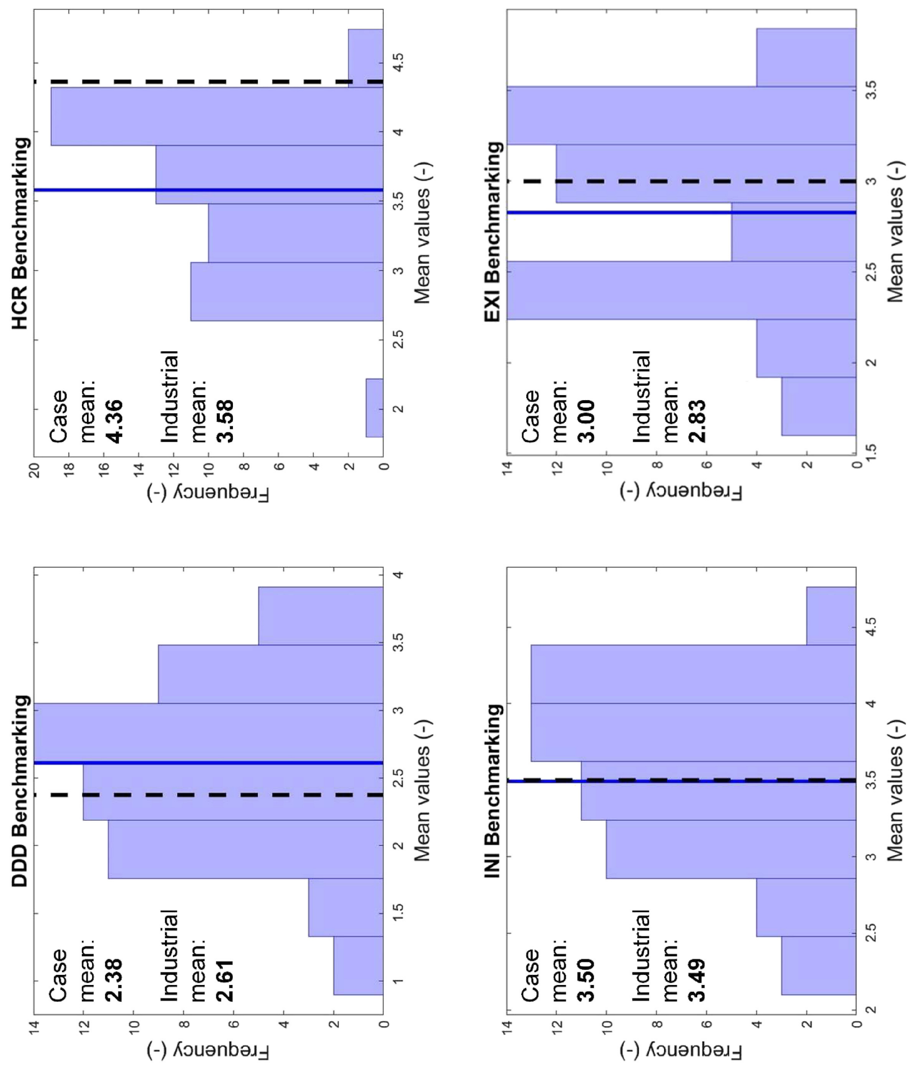


Figure 4.
Benchmarking figures from Case 1

were suggested, for example, education in smart maintenance (HCR dimension) and involvement of the IT department (INI dimension). There was also a strong emphasis on creating a common vision and establishing goals that aligned with the company's overall goals. Afterward, the material was collected, compiled digitally and returned to the case company for further development.

The main experience was that the assessment engaged the employees. Moreover, it seemed that the case company seldom had time to discuss its issues, specifically those relating to the questions about the measurement instrument, smart maintenance and strategy in general.

From the documentation regarding the further development of a smart maintenance strategy, it can be seen that the company has aligned its smart maintenance goals with those of the company. Due to a reorganization, the maintenance manager needed to focus on internal communication with new management groups to present how smart maintenance will contribute to the goals of the company. Meanwhile, the maintenance organization has continued its work by evaluating different technological solutions and updating its activity plan with smart maintenance activities. This activity plan is transparent within the company, and there is monthly follow-up. During the focus group, the maintenance manager highlighted the fact that the material developed was very useful in communicating with management.

In summary, Table 1 describes interesting findings and supporting evidence from Case 1.

4.2 Within-case analysis 2

The second case in this study concerns a process industry company. In this case, a smart maintenance assessment was done beforehand (before the workshop). Twenty people answered the questionnaire. From the 20 different answers, the median for each question was used as input to the benchmarking tool. Before the workshop, the researchers prepared results (a density plot) of each of the dimensions of smart maintenance. These are presented in Figure 5.

The company in Case 2 scored 3 on DDD, 4.18 on HCR, 3.50 on INI and 3 on EXI.

Eighteen of the 20 people who did the assessment were able to participate in the workshop, which started with a presentation of the results. This led to in-depth discussions about the implications of the results and how they can be translated into actions within their organization. Although not directly linked to the company's development toward smart maintenance, the researcher's interpretation was that this constituted an important form of motivation as to why this development was taking place.

During the workshop, many of the suggested activities were related to technology and the DDD dimension of smart maintenance. However, additional activities were also suggested, such as creation and communication of vision and goals, responsibility assignment, involvement of the technology department and the production department, and competence development. The material was collected, compiled digitally and returned to the case company for further development.

From the documentation of the ongoing smart maintenance strategy work, it is clear that the case company has focused on three established values. They expressed a need to align smart maintenance with something inbuilt within the company, to avoid resistance to something new. The material collected by the researcher during the workshop was discussed and developed by the maintenance management group, to set a roadmap of activities. Each activity was color-coded according to the company's values. This made it easy to understand the purpose of each activity. All smart maintenance-related activities were integrated with the company's regular activity plans. These plans are followed up regularly. The major challenge for this company was gathering all the competencies needed to start things off. However, there was greater interest from the rest of the organization when it was pointed out that the benchmarking tool had been developed through research.

Finding	Supporting evidence	Data source
Employee engagement	Intense discussions were observed during the assessment using the measurement instrument and during the workshop	Participant observation
Rare joint development discussions	Interpretation of the intense discussions observed during the assessment using the measurement instrument and during the workshop	Participant observation
Interplay among the four dimensions	At the beginning of the workshop, the suggested activities were related to the DDD dimension. As the workshop went by, activities emphasizing the other dimensions of smart maintenance were also suggested. Later on, it was clear that they were considering all four dimensions in their strategy	Participant observation Documentation Focus group
Internal communication	The case company spent much time on internal communication about smart maintenance	Documentation Focus group
The developed material supported internal communication to management	Changing internal customer (i.e. re-organization, management turnover) requires repeated internal communication. It was clear that the developed material was useful in helping the maintenance manager communicate clearly about smart maintenance and the development plan	Documentation Focus group
Strategic alignment	The goal of smart maintenance was clearly connected to the company's goals	Documentation Focus group
Planning and scheduling activities	Activities from the smart maintenance roadmap were integrated into the existing long-term action plan	Documentation Focus group
Follow-up	Activities and effects will be followed up each month (established follow-up of the long-term action plan)	Documentation Focus group
Daily work disrupting long-term work	It was stated that the development of the roadmap and strategy needed to be down-prioritized due to "urgent things" in their daily work (i.e. short term vs long term)	Documentation Focus group
Discussing technology was easy	The participants suggested many activities related to the DDD dimension during the workshop. During the development work, there was much discussion and evaluation of tools for machine health assessment	Participant observation Documentation

Table 1.
Key findings from Case 1, with supporting evidence

The findings and supporting evidence from Case 2 are summarized in Table 2.

4.3 Within-case analysis 3

Case 3 is an infrastructure and traffic service company. This company realized that it must involve its contractors to successfully implement smart maintenance. The company decided to invite its external maintenance partners to participate in the assessment and subsequent workshop. Nine people completed the questionnaire and the median of those nine responses was used as input to the benchmarking tool. The researchers prepared results (a density plot) for each of the smart maintenance dimensions, see Figure 6.

The company in Case 3 scored 2.75 on DDD, 3.64 on HCR, 3.38 on INI and 3.22 on EXI.

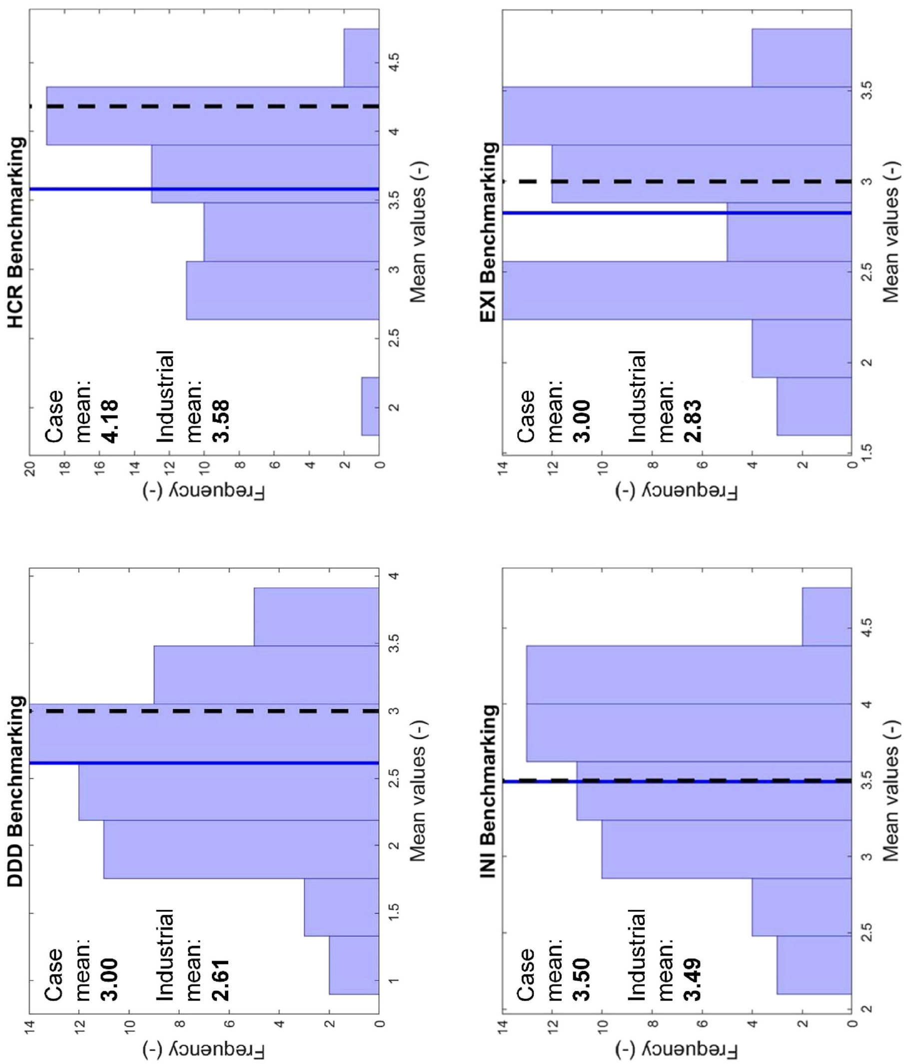


Figure 5.
Benchmarking figures
from Case 2

Table 2.
Key findings from Case 2, with supporting evidence

Finding	Supporting evidence	Data source
Employee engagement	Intense discussions during the presentation of the assessment results and during the workshop	Participant observation
Interplay among the four dimensions	Many of the suggested activities were related to the DDD dimension. However, additional activities considering other aspects than DDD was suggested, and all four dimensions were considered in their future development of the roadmap	Participant observation Documentation Focus group
Internal communication	The case company linked smart maintenance with the company's values so as not to "bring in a new concept" and create resistance	Documentation Focus group
Strategic alignment	The activities in the roadmap were connected to the company's values (and instructively color-coded to each of the values)	Documentation Focus group
Planning and scheduling activities	Activities from the smart maintenance roadmap were integrated into the company's regular plans	Documentation Focus group
Follow-up	Activities and effects will be followed up regularly (i.e. integrated into established follow-up routines	Documentation Focus group
Difficulty getting it done	Interpretation that this has been on the agenda for some time (mature discussions). But based on its own work, the company had experienced difficulty gathering all necessary competencies to continue development	Participant observation Documentation Focus group
Research adds credibility	Interest and response from the rest of the organization greater when it was pointed out that the work was based on research	Focus group

The results were presented at the workshop, in which 11 (internal and external people) participated. The initial focus of the workshop was on the DDD dimension. Many associated activities were suggested at the beginning of the workshop, such as inventorying data, connecting more internal data sources and adding sensors. As the workshop proceeded, the suggested activities covered other aspects, for example, defining goals, training maintenance personnel, starting different pilot projects, training people to interpret algorithms and efforts to retain the mindset (of willingness to implement change) among current and future management groups. A recurrent issue in the company's roadmap was starting on a small scale, testing the proposal and then scaling up the use of new technology. This company also acknowledges the importance of highlighting progress and taking time to reflect and indeed to celebrate. From an observation point of view, it was not obvious that external parties were participating in the workshop. The material was collected, compiled digitally and returned to the case company for further development.

After the workshop, the company worked with its external parties to further develop its smart maintenance strategy. The documentation revealed that the participants had continued with their discussions and workshops and compiled a final plan to present to the company management. One of the most-discussed issues (as stated in the documentation) was the anticipated effects of smart maintenance. This was also highlighted by what the company considers to be a challenge; quantifying the long-term effects, defining clear goals and selecting PIs for short- and long-term measurement. The work of this study will be integrated with the strategic maintenance development plan. Goals will be set to keep long-term track of the development but will also include more operational measures, followed up each month.

Summarizing Case 3, interesting findings and supporting evidence are described in Table 3.

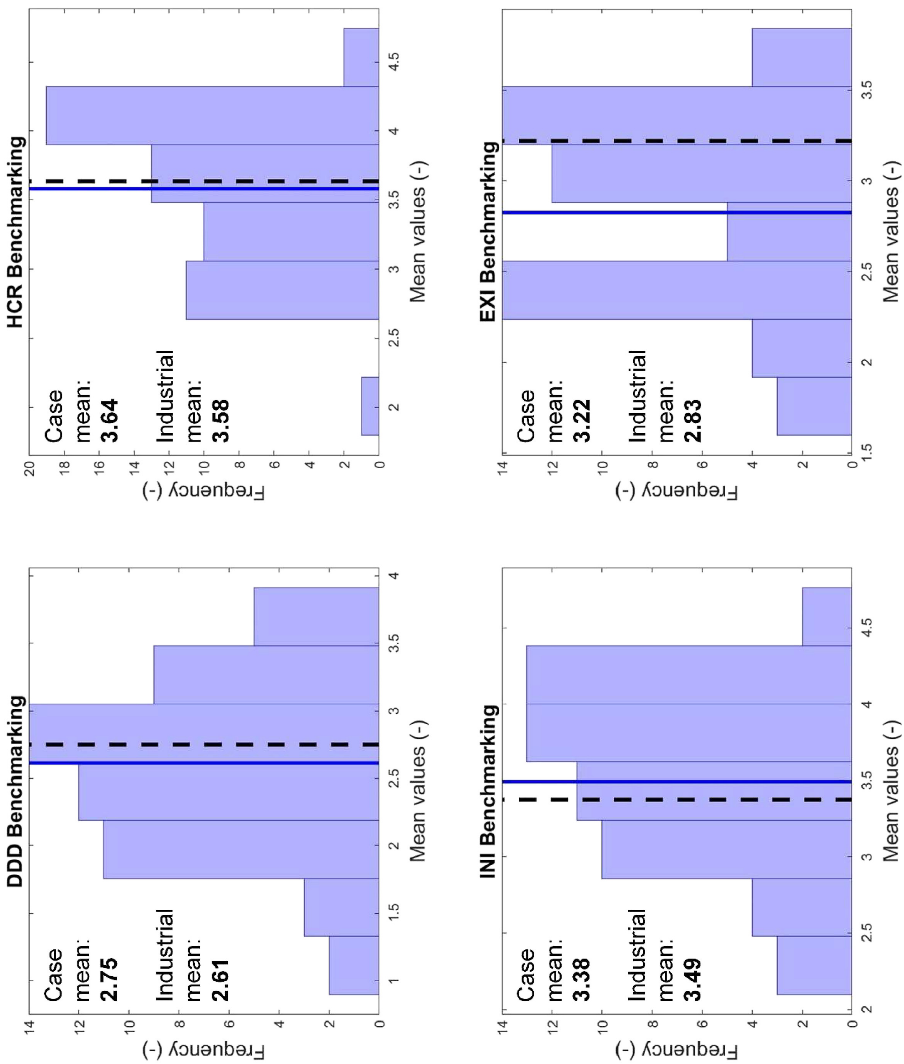


Figure 6.
Benchmarking figures
from Case 3

Table 3.
Key findings from Case 3, with supporting evidence

Finding	Supporting evidence	Data source
Employee engagement	Intense discussions during the presentation of the assessment results and during the workshop	Participant observation
Interplay among the four dimensions	DDD was initially the focus during the workshop, as many associated activities were suggested at the beginning of the workshop. As the workshop went by, the suggested activities covered other aspects, including the other dimensions of smart maintenance. Especially, they had a high degree of involvement by their most important suppliers (EXI)	Participant observation Documentation Focus group
Internal communication	More workshops and discussions were held and material compiled to present to the management group	Documentation Focus group
Strategic alignment	The goal of smart maintenance clearly connected to the company's goals	Documentation Focus group
Planning and scheduling activities	Activities from the smart maintenance roadmap were integrated into the company's (existing) overall maintenance development plan	Documentation Focus group
Follow-up	Activities and effects will be followed up each month	Documentation Focus group
Difficulty identifying relevant PIs for follow-up	The general challenge was noted, of quantifying the effects of digitalization and identifying relevant PIs to track the impact of the company's change	Documentation Focus group
Challenging system integration	The case company sees itself as strong on INI and EXI of people. By contrast, it needs to improve its system integration	Participant observation Documentation

4.4 Cross-case analysis

A cross-case analysis was conducted to identify similarities and differences between the findings from the cases. By comparing the results from each of the cases, two main patterns of the findings could be observed. The findings were (1) identified in all cases or (2) identified in only one of the cases.

Six main themes emerged from the empirical findings. These themes are likely to be important for successful strategy development: *employee engagement, interplay among the dimensions, internal communication, strategic alignment, planning and scheduling activities and follow-up*. All case companies stressed that smart maintenance must be aligned with what the company is already doing if there is to be support from both management and employees. Thus, the ability to communicate the concept of smart maintenance becomes crucial. Initiated by Case 3, the ability to follow-up planned activities and their effects were also discussed. The participants were emphatic in stressing the challenges of selecting indicators; they felt it was difficult to know the effects of digitalization in general and smart maintenance in particular. Nevertheless, all companies agreed that the smart maintenance measurement instrument generated employee engagement. Firstly, the employees gave their opinions by assessing the current state of the maintenance organization. The smart maintenance measurement instrument provides a clear, visual result, which may serve as a non-biased basis for discussing potential improvements.

In addition to the findings common to all cases, there were some unique findings in each of the cases. For example, Case 1 emphasized the challenge in daily work disruption long-term development, Case 2 could use the research label for credibility from the rest of the organization and Case 3 highlighted the technological challenges in system integration. These differences might be firm-specific and dependent on the company's character and maturity, but will not be analyzed further. The themes present in all cases are interpreted as important factors for successful strategy development. Table 4 gives an overview of all findings from each of the three cases.

4.5 Theoretical interpretations

The six themes from the cross-case analysis show that the perception of maintenance strategies needs to be revised. A selection of corrective/reactive, preventive and condition-based maintenance (Al-Najjar and Alsyouf, 2003; Bevilacqua and Braglia, 2000; Gutschi *et al.*, 2019; Ilangkumaran and Kumanan, 2009; Shyjith *et al.*, 2008; Tan *et al.*, 2011; Wang *et al.*, 2007) might not suffice to support the development of maintenance in digitalized manufacturing. Instead, the case companies formulated their strategy including organizational development with operational employees involved (Jarzabkowski *et al.*, 2007) to achieve *employee engagement* (Veile *et al.*, 2020). This approach allows a mixture of top-down and bottom-up approaches (Mintzberg and Waters, 1985); the strategy reflects the day-to-day practice and thus evolves (Jarzabkowski *et al.*, 2007; Whittington, 2004) with the development of the maintenance organization.

A smart maintenance measurement instrument (Bokrantz *et al.*, 2020a) was used to provide a clear, visual current state of the maintenance organization, including benchmarking. Presenting the benchmarking results and identifying activities for improvement in a workshop format were successful for creating *employee engagement* and including discussions from different perspectives, as reported by Phaal *et al.* (2007) and Phaal and Muller (2009). The participants started the workshop by suggesting many activities related to the DDD dimension. As the workshop proceeded, the participants realized that there is *an interplay among the four dimensions*. Activities considering the other dimensions of smart maintenance were suggested and placed accordingly in the roadmap. All four dimensions are defining characteristics of smart maintenance, and the activities within each dimension need to be executed in the right sequence. Thus, a strategic priority helps in *planning and scheduling activities* within the four dimensions. Roadmapping is a particularly useful method to visualize and facilitate *internal communication* of important activities and overall strategies, (Elbanna *et al.*, 2016; Phaal and Muller, 2009; Ghobakhloo, 2018) and can thus be beneficial for smart maintenance strategies.

The importance of *strategic alignment* has previously been established; a strategy must be aligned with the goals of the company and consider the context to lead to performance (Dangayach and Deshmunk, 2001; Galbraith and Schendel, 1983). Similarly, the cases in this study show a clear connection between a company's goals and its maintenance organization's

Finding	Case 1	Case 2	Case 3
Employee engagement	X	X	X
Rare joint development discussions	X		
Interplay among the four dimensions	X	X	X
Internal communication	X	X	X
The developed material supported internal communication to management	X		
Strategic alignment	X	X	X
Planning and scheduling activities	X	X	X
Follow-up	X	X	X
Daily work disrupting long-term work	X		
"Easy" to discuss technology	X		
Difficult to "get it done"		X	
Research for credibility		X	
Difficult identifying relevant PIs for follow up			X
Challenging system integration			X

Table 4. Summary of the cross-case analysis, including the findings from each of the three cases

contribution; the case companies were able to work on *strategic alignment* to effectively (and successfully) communicate about smart maintenance to top-level management and employees. A clear example of new insight into how to develop a maintenance strategy is from Case 2, where they formulated the smart maintenance strategy in connection with the company's fundamental values. As the values are well recognized by the employees, this kind of alignment connects the individual to the maintenance organization and, further, to the overall company. The connection between individuals and their contribution to the overall company, which creates value-fit, was not clear in all cases. However, research on smart maintenance strategies would benefit from applying value-fit to a larger extent. Value-fit facilitates desirable attitudes (Klein and Sorra, 1996) and creates the *employee engagement* needed (Veile *et al.*, 2020) for successful implementation.

The case companies emphasized the importance of *follow-up* on the smart maintenance initiatives. This was considered difficult and can be partly explained by the technical focus of maintenance PIs (Salonen and Bengtsson, 2011). In the same way that strategic change requires modifying pre-existing PIs (Braz *et al.*, 2011; Simões *et al.*, 2016), a smart maintenance strategy requires a set of PIs that are appropriate and aligned with smart maintenance (Lundgren *et al.*, 2020).

5. A strategy development process for Smart Maintenance

Based on the six emergent themes from the cross-case analysis and the interpretations grounded in the theoretical framework, we propose a cyclic process of strategy development for smart maintenance comprised of six steps: (1) benchmarking using a smart maintenance measurement instrument, (2) setting clear goals, (3) setting strategic priority, (4) planning key activities, (5) elevating implementation and (6) follow-up. This cyclic process is presented in Figure 7.

(1) Using a smart maintenance measurement instrument (Bokrantz *et al.*, 2020a) to assess and benchmark the maintenance organization gives employees an understanding of the four dimensions of smart maintenance in their organization and helps them identify improvement areas. The visualization of the results from the measurement instrument created *employee engagement*, which supports a mixture of top-down and bottom-up approaches to strategy development (Jarzabkowski *et al.*, 2007; Mintzberg and Waters, 1985).

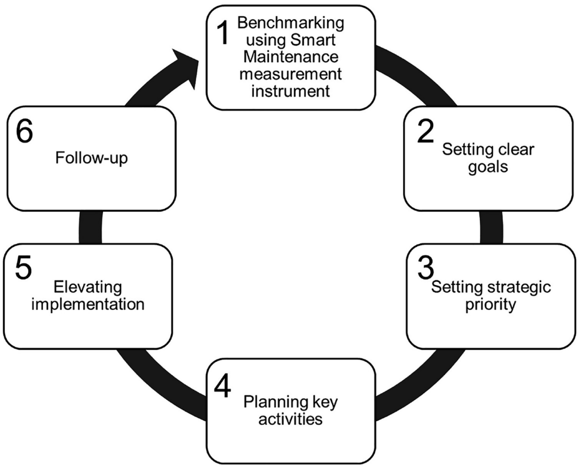


Figure 7.
The cyclic process includes six different steps in strategy development

(2) Companies should set goals for desirable outcomes of smart maintenance; this relates to broader aspects than technical availability. There must be a clear link between the maintenance strategy and the company's goals, i.e. *strategic alignment* (Dangayach and Deshmunk, 2001; Galbraith and Schendel, 1983), as well as the maintenance employees' individual goals to create value-fit (Klein and Sorra, 1996), thus maintain *employee engagement. Internal communication* of the goals is essential to successfully engage the entire organization.

(3) There is an *interplay among the four dimensions,* making it important to set a strategic priority to ensure that the activities are executed in the right sequence. The strategic priority helps in *planning and scheduling activities* for each of the dimensions of smart maintenance. The priority could preferably be based on the results of the smart maintenance measurement instrument (Step 1).

(4) Activities to improve the prioritized dimension must be identified and planned, to reach the desired goals. A good start to identify activities is to bring together the employees for a brainstorming workshop. This provides dialogue and creates *employee engagement* (Phaal *et al.*, 2007; Phaal and Muller, 2009). It might also be possible to involve external parties, to gain inspiration from "best practice." Nevertheless, activities can advantageously be visualized in a roadmap to clearly show *the planning and scheduling of activities* and facilitate *internal communication* of the strategy (Elbanna *et al.*, 2016; Phaal and Muller, 2009; Ghobakhloo, 2018).

(5) Elevating implementation by putting planned activities into action. However, to gain an effect from these activities, the context (including external and internal factors) must be considered (Dangayach and Deshmunk, 2001; Galbraith and Schendel, 1983). Many factors influence (facilitate or inhibit) the implementation of smart maintenance (Bokrantz *et al.*, 2020b), such as culture, leadership, technology investments and IT security. Assessing the company relative to these factors means that implementation may be elevated by using the company's strengths and by being attentive to potential obstacles.

(6) Subsequently, it is important to *follow-up* on the activities and their impact/effect and link this back to the company's goals and the goals of individual employees (Klein and Sorra, 1996). PIs within the maintenance organization should not be limited to technical aspects, such as technical availability and equipment failure rates. Rather, they must consider aspects such as financial performance on a company level and job satisfaction on an employee level (Lundgren *et al.*, 2020). Changes in strategy require changed PIs (Braz *et al.*, 2011; Simões *et al.*, 2016); succeeding with a smart maintenance strategy means updating the set of PIs. Furthermore, *follow-up* on progress is crucial to maintain *employee engagement* (Boer and During, 2001). Thus, it becomes important to communicate the progress of the smart maintenance implementation and highlight accomplishments within all of the four dimensions.

A new assessment with the smart maintenance measurement instrument enables the identification of potential new improvement possibilities for the maintenance organization. When regularly assessing and benchmarking the maintenance organization, strategy development becomes a mixture of top-down and bottom-up approaches (Jarzabkowski *et al.*, 2007; Mintzberg and Waters, 1985). Using the perspective of strategy-as-practice increases the likelihood of gaining maintenance employee engagement with strategy development. Ultimately, this benefits the company's development.

6. Discussion

Research has previously highlighted the importance of organizational aspects for developing holistic strategies for maintenance in general (Bengtsson and Salonen, 2009; Tsang, 1998) and for smart maintenance in particular (Bokrantz *et al.*, 2020b). However, there has been little research focusing on the work procedure for developing such strategies (Silvestri *et al.*, 2020). To provide a holistic understanding of the development of smart maintenance strategies, we followed three industrial case companies' development of strategies for smart maintenance. Thereby, we make a range of important contributions. This study and its contributions are summarized in Figure 8.

Firstly, we propose a novel process for maintenance strategy development. Six themes for successful strategy development emerged from the cross-case analysis. These empirical findings were combined with the theoretical framework to provide a clear, step-by-step process for successful strategy development. Previous research has highlighted that such strategies are important for maintenance in general (Bengtsson and Salonen, 2009; Tsang, 1998), and maintenance in digitalized manufacturing in particular (Bokrantz *et al.*, 2020b; Silvestri *et al.*, 2020). This study provides a structured process for developing such strategies.

Secondly, we contribute with a new perspective on maintenance strategies. A maintenance strategy has long been considered as a selection of corrective/reactive, preventive and condition-based maintenance (Al-Najjar and Alsyouf, 2003; Bevilacqua and Braglia, 2000; Gutschi *et al.*, 2019; Ilangkumaran and Kumanan, 2009; Shyjith *et al.*, 2008; Tan *et al.*, 2011; Wang *et al.*, 2007). By contrast, the way the maintenance strategies were developed in the cases shows that a maintenance strategy is not limited to a plan for equipment repair, but also includes a holistic perspective for organizational development. This new perspective promotes employee involvement with a mixture of top-down and bottom-up approaches. The strategy reflects what is done in practice and becomes dynamic, which is referred to as the perspective of strategy-as-practice (Jarzabkowski *et al.*, 2007; Mintzberg and Waters, 1985). This view on maintenance strategies makes the strategy evolve over time and supports the continuous development of the maintenance organization to make it ready for the demands of digitalized manufacturing.

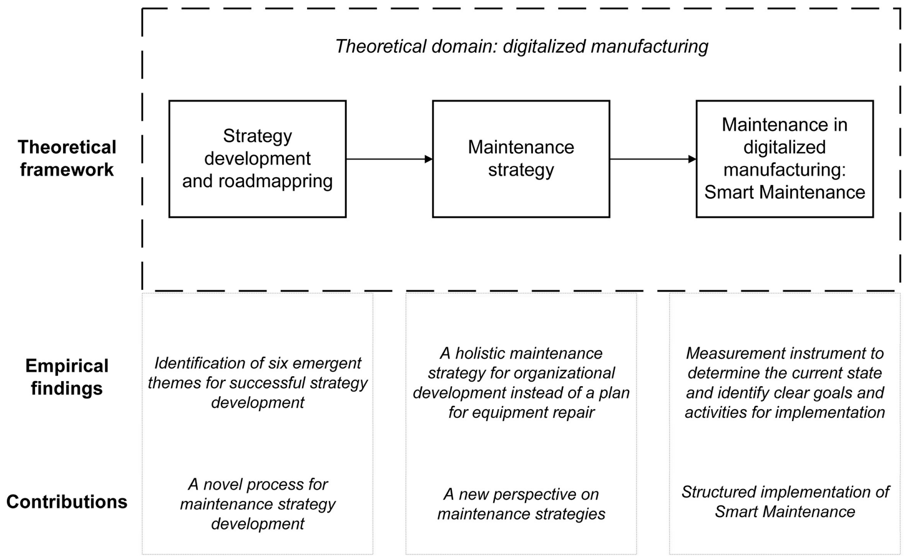


Figure 8.
A summary of the study: the contributions of the empirical findings in the theoretical domain of digitalized manufacturing

Thirdly, the clear step-by-step process (Section 5) supports a structured implementation of smart maintenance. The managerial implication is that industry practitioners can apply the new perspective of maintenance strategies by following the proposed process. Moreover, the authentic description of three industrial cases provides industry practitioners with clear examples of how to develop a maintenance strategy, which is rare in research about maintenance in digitalized manufacturing (Silvestri *et al.*, 2020).

There are various maintenance concepts for maintenance in digitalized manufacturing, with a varied use of terminology causing a lack of concept clarity (Bokrantz *et al.*, 2020c, and Huang *et al.*, 2020). Also, there are numerous maturity models to assess maintenance organizations, e.g. Nemeth *et al.* (2019), Oliveira and Lopes (2019) and Poór *et al.* (2019). Maturity models are easy to use and allow a quick assessment of the maintenance function. From such assessment, potential improvement areas can be identified and serve as input for strategy development in individual companies. However, maturity models are rarely aligned with the concepts that describe maintenance in digitalized manufacturing, therefore lacking concept-measure consistency (Becker *et al.*, 2010). To bring clarity in strategy development for maintenance in digitalized manufacturing, the proposed process has been developed based on the concept of smart maintenance (Bokrantz *et al.*, 2020c), including assessment of maintenance organizations using a smart maintenance measurement instrument (Bokrantz *et al.*, 2020a). From a practical point of view, other assessment methods, such as maturity models, may work with our proposed process, to develop maintenance strategies. Therefore, it could be valuable to test our proposed process in conjunction with other assessment methods.

The authors acknowledge some limitations of the study. We used purposive sampling to study three cases regarding their smart maintenance strategy development. The cases were sampled based on three criteria (see Section 3), and companies without dedicated resources (e.g. common among small and medium enterprises (SMEs)) were, therefore, not included in the sample. Variation in geographical location might also contribute to cultural differences between maintenance organizations; this was not considered in this study, as the sampled cases were all from the Swedish industry. The process is based on the smart maintenance concept described by Bokrantz *et al.* (2020c) and the associated measurement instrument (Bokrantz *et al.*, 2020a). However, it could also be possible to couple the proposed strategy process in this paper (Figure 7) with other concepts and assessment methods.

We recommend future research where the proposed process is used to create smart maintenance strategies in more companies, for validation and/or further development of the process. Finally, we recommend future research to elaborate on the steps in the proposed process, to more in detail describe what becomes important in each step. These research activities can help in developing this perspective of maintenance strategy and determine how it stimulates the development of the maintenance organizations and, further, their performance.

7. Conclusion

This paper contributes with a new way of perceiving and developing maintenance strategies. A cyclic process for strategy development is proposed, to stimulate the development of maintenance organizations and support the implementation of smart maintenance. The proposed process is based on the empirical findings from this study and theoretical interpretations. It includes six steps:

(1) Benchmarking using a smart maintenance measurement instrument;

(2) Setting clear goals;

(3) Setting strategic priority;

(4) Planning key activities;

(5) Elevating implementation; and

(6) Follow-up.

The managerial implication is the guidance of maintenance managers in the development of a clear smart maintenance strategy. The proposed process endorses the development of a maintenance strategy based on the current state of the maintenance organization and supports a mixture of top-down and bottom-up approaches. It creates engagement among maintenance employees and will ultimately contribute to companies' long-term development.

This study focused on developing a process for smart maintenance strategy development and did not include testing of the process. The authors, thus, recommend future research to test the proposed process and follow-up its impact on organizational development and performance. Especially, the authors recommend future research to elaborate on the steps in the proposed process. These research activities can help in providing more detailed insights into each of the steps in the proposed process and thereby further stimulate the development of maintenance organizations and make them ready for digitalized manufacturing.

References

Adler, P.A. and Adler, P. (1994), "Observational techniques", *Handbook of Qualitative Research*, Sage Publications, Thousand Oaks, CA, pp. 377-392.

Akkermans, H., Besselink, L., van Dongen, L. and Schouten, R. (2016), *Smart Moves For Smart Maintenance: Findings from A Delphi Study on 'Maintenance Innovation Priorities' for The Netherlands*, World Class Maintenance.

Al-Najjar, B. and Alsyouf, I. (2003), "Selecting the most efficient maintenance approach using fuzzy multiple criteria decision making", *International Journal of Production Economics*, Vol. 84 No. 1, pp. 85-100, doi: 10.1016/S0925-5273(02)00380-8.

Antil, P. (1991), "The maintenance organizational maturity grid", *Maintec Conference*, COMAC Publications, Birmingham, March.

Barratt, M., Choi, T.Y. and Li, M. (2011), "Qualitative case studies in operations management: trends, research outcomes, and future research implications", *Journal of Operations Management*, Vol. 29 No. 4, pp. 329-342.

Becker, J., Niehaves, B., Pöppelbuß, J. and Simons, A. (2010), "Maturity models in IS research", *18th European Conference on Information Systems, ECIS 2010*, Pretoria, available at: https://aisel.aisnet.org/ecis2010/42/ (accessed 2 September 2020).

Bengtsson, M. and Salonen, A. (2009), "On the need for research on holistic maintenance", *Paper Presented at the Proceedings of the 22th international congress on Condition Monitoring and Diagnostic Engineering Management (COMADEM)*, 9-11 June, San Sebastian, Spain.

Bevilacqua, M. and Braglia, M. (2000), "The analytic hierarchy process applied to maintenance strategy selection", *Reliability Engineering and System Safety*, Vol. 70 No. 1, pp. 71-83, doi: 10.1016/S0951-8320(00)00047-8.

Boer, H. and During, W.E. (2001), "Innovation, what innovation? A comparison between product, process and organizational innovation", *International Journal of Technology Management*, Vol. 22 Nos 1-3, pp. 83-107.

Bokrantz, J., Skoogh, A., Berlin, C. and Stahre, J. (2017), "Maintenance in digitalised manufacturing: delphi-based scenarios for 2030", *International Journal of Production Economics*, Vol. 191, pp. 154-169, doi: 10.1016/j.ijpe.2017.06.010.

Bokrantz, J., Skoogh, A., Berlin, C. and Stahre, J. (2020a), "Smart maintenance: instrument development, content validation and an empirical pilot", *International Journal of Operations and Production Management*, Vol. 40 No. 4, pp. 481-506, doi: 10.1108/ijopm-11-2019-0746.

Bokrantz, J., Skoogh, A., Berlin, C., Wuest, T. and Stahre, J. (2020b), "Smart Maintenance: a research agenda for industrial maintenance management", *International Journal of Production Economics*, Vol. 224, doi: 10.1016/j.ijpe.2019.107547.

Bokrantz, J., Skoogh, A., Berlin, C., Wuest, T. and Stahre, J. (2020c), "Smart Maintenance: an empirically grounded conceptualization", *International Journal of Production Economics*, Vol. 223, doi: 10.1016/j.ijpe.2019.107534.

Braz, R.G.F., Scavarda, L.F. and Martins, R.A. (2011), "Reviewing and improving performance measurement systems: an action research", *International Journal of Production Economics*, Vol. 133 No. 2, pp. 751-760.

Carnero, M.C. (2005), "Selection of diagnostic techniques and instrumentation in a predictive maintenance program. A case study", *Decision Support Systems*, Vol. 38 No. 4, pp. 539-555.

Chemweno, P., Pintelon, L., Van Horenbeek, A. and Muchiri, P.N. (2015), "Asset maintenance maturity model: structured guide to maintenance process maturity", *International Journal of Strategic Engineering Asset Management*, Vol. 2 No. 2, pp. 119-135, doi: 10.1504/ijseam.2015.070621.

Compare, M., Baraldi, P. and Zio, E. (2020), "Challenges to IoT-enabled predictive maintenance for industry 4.0", *IEEE Internet of Things Journal*, Vol. 7 No. 5, pp. 4585-4597, doi: 10.1109/jiot.2019.2957029.

Corley, K.G. and Gioia, D.A. (2004), "Identity ambiguity and change in the wake of a corporate spinoff", *Administrative Science Quarterly*, Vol. 49 No. 2, pp. 173-208.

Culot, G., Nassimbeni, G., Orzes, G. and Sartor, M. (2020), "Behind the definition of industry 4.0: analysis and open questions", *International Journal of Production Economics*, Vol. 226, 107617.

Dangayach, G. and Deshmukh, S. (2001), "Manufacturing strategy", *International Journal of Operations and Production Management*, Vol. 21 No. 7, pp. 884-932.

Denscombe, M. (2014), *The Good Research Guide: For Small-Scale Social Research Projects*, McGraw-Hill Education, Berkshire.

Elbanna, S., Andrews, R. and Pollanen, R. (2016), "Strategic planning and implementation success in public service organizations: evidence from Canada", *Public Management Review*, Vol. 18 No. 7, pp. 1017-1042.

Flynn, B.B., Sakakibara, S., Schroeder, R.G., Bates, K.A. and Flynn, E.J. (1990), "Empirical research methods in operations management", *Journal of Operations Management*, Vol. 9 No. 2, pp. 250-284.

Flynn, B., Pagell, M. and Fugate, B. (2018), "Survey research design in supply chain management: the need for evolution in our expectations", *Journal of Supply Chain Management*, Vol. 54 No. 1, pp. 1-15.

Galar, D., Thaduri, A., Catelani, M. and Ciani, L. (2015), "Context awareness for maintenance decision making: a diagnosis and prognosis approach", *Measurement: Journal of the International Measurement Confederation*, Vol. 67, pp. 137-150, doi: 10.1016/j.measurement.2015.01.015.

Galbraith, C. and Schendel, D. (1983), "An empirical analysis of strategy types", *Strategic Management Journal*, Vol. 4 No. 2, pp. 153-173.

Ghobakhloo, M. (2018), "The future of manufacturing industry: a strategic roadmap toward Industry 4.0", *Journal of Manufacturing Technology Management*, Vol. 29 No. 6, pp. 910-936.

Glaser, B.G. and Strauss, A.L. (1967), *The Discovery of Grounded Theory: Strategies for Qualitative Theory*, Aldine Transaction, New Brunswick.

Grubic, T. and Peppard, J. (2016), "Servitized manufacturing firms competing through remote monitoring technology an exploratory study", *Journal of Manufacturing Technology Management*, Vol. 27 No. 2, pp. 154-184, doi: 10.1108/jmtm-05-2014-0061.

Gutschi, C., Furian, N., Voessner, S., Graefe, M. and Kolios, A. (2019), "Evaluating the performance of maintenance strategies: a simulation-based approach for wind turbines", in Mustafee, N., Bae, K.-H.G., Lazarova-Molnar, S., Rabe, M., Szabo, C., Haas, P. and Son, Y.-J., (Eds), *2019 Winter Simulation Conference (WSC)*, IEEE, pp. 842-853.

Huang, F., Chen, J., Sun, L., Zhang, Y. and Yao, S. (2020), "Value-based contract for smart operation and maintenance service based on equitable entropy", *International Journal of Production Research*, Vol. 58 No. 4, pp. 1271-1284.

Ilangkumaran, M. and Kumanan, S. (2009), "Selection of maintenance policy for textile industry using hybrid multi-criteria decision making approach", *Journal of Manufacturing Technology Management*, Vol. 20 No. 7, pp. 1009-1022.

Jarzabkowski, P., Balogun, J. and Seidl, D. (2007), "Strategizing: the challenges of a practice perspective", *Human Relations*, Vol. 60 No. 1, pp. 5-27, doi: 10.1177/0018726707075703.

Kagermann, H., Helbig, J., Hellinger, A. and Wahlster, W. (2013), *Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0: Securing the Future of German Manufacturing Industry*, final report of the Industrie 4.0 Working Group, Forschungsunion.

Kawulich, B.B. (2005), "Participant observation as a data collection method", *Forum Qualitative Sozialforschung/Forum: Qualitative Social Research*, Vol. 6 No. 2, Art. 43.

Klein, K.J. and Sorra, J.S. (1996), "The challenge of innovation implementation", *Academy of Management Review*, Vol. 21 No. 4, pp. 1055-1080.

Kumar, U. and Galar, D. (2018), "Maintenance in the era of industry 4.0: issues and challenges", in Kapur, P., Kumar, U. and Verma, A. (Eds), *Quality, IT and Business Operations*, Springer, pp. 231-250, doi: 10.1007/978-981-10-5577-5_19.

Lee, J., Ni, J., Djurdjanovic, D., Qiu, H. and Liao, H. (2006), "Intelligent prognostics tools and e-maintenance", *Computers in Industry*, Vol. 57 No. 6, pp. 476-489.

Lee, J., Wu, F., Zhao, W., Ghaffari, M., Liao, L. and Siegel, D. (2014), "Prognostics and health management design for rotary machinery systems—reviews, methodology and applications", *Mechanical Systems and Signal Processing*, Vol. 42 Nos 1-2, pp. 314-334.

Lee, J., Ardakani, H.D., Yang, S. and Bagheri, B. (2015), "Industrial big data analytics and cyber-physical systems for future maintenance and service innovation", *Procedia CIRP*, Vol. 38, pp. 3-7, doi: 10.1016/j.procir.2015.08.026.

Li, Z., Wang, Y. and Wang, K.-S. (2017), "Intelligent predictive maintenance for fault diagnosis and prognosis in machine centers: industry 4.0 scenario", *Advances in Manufacturing*, Vol. 5 No. 4, pp. 377-87, doi: 10.1007/s40436-017-0203-8.

Lu, Y. (2017), "Industry 4.0: a survey on technologies, applications and open research issues", *Journal of Industrial Information Integration*, Vol. 6, pp. 1-10, doi: 10.1016/j.jii.2017.04.005.

Lundgren, C., Bokrantz, J. and Skoogh, A. (2020), "Measuring the effects of Smart Maintenance using industrial performance indicators", *Journal of Productivity and Performance Management*, 1741-0401, doi: 10.1108/ijppm-03-2019-0129.

Macchi, M. and Fumagalli, L. (2013), "A maintenance maturity assessment method for the manufacturing industry", *Journal of Quality in Maintenance Engineering*, Vol. 19 No. 3, pp. 295-315, doi: 10.1108/jqme-05-2013-0027.

Macchi, M., Roda, I. and Fumagalli, L. (2017), "On the advancement of maintenance management towards smart maintenance in manufacturing", in Lödding, H., Riedel, R., Thoben, K.D., von Cieminski, G. and Kiritsis, D. (Eds), *IFIP International Conference on Advances in Production Management Systems, IFIP AICT 513*, Springer, Cham, pp. 383-390, doi: 10.1007/978-3-319-66923-6_45.

Mehairjan, R.P., van Hattem, M., Djairam, D. and Smit, J.J. (2016), "Development and implementation of a maturity model for professionalising maintenance management", in Koskinen, K.T. *et al.* (Eds), *Proceedings of the 10th World Congress on Engineering Asset Management (WCEAM 2015)* Springer, Cham, pp. 415-427, doi: 10.1007/978-3-319-27064-7_40.

Mento, A., Jones, R. and Dirndorfer, W. (2002), "A change management process: grounded in both theory and practice", *Journal of Change Management*, Vol. 3 No. 1, pp. 45-59.

Mintzberg, H. and Waters, J.A. (1985), "Of strategies, deliberate and emergent", *Strategic Management Journal*, Vol. 6 No. 3, pp. 257-272.

Mintzberg, H., Ahlstrand, B. and Lampel, J. (2005), *Strategy Safari: A Guided Tour through the Wilds of Strategic Management*, Simon and Schuster, New York, NY.

Muller, A., Marquez, A.C. and Iung, B. (2008), "On the concept of e-maintenance: review and current research", *Reliability Engineering and System Safety*, Vol. 93 No. 8, pp. 1165-1187.

Munzinger, C., Fleischer, J., Broos, A., Hennrich, H., Wieser, J., Ochs, A. and Schopp, M. (2009), "Development and implementation of smart maintenance activities for machine tools", *CIRP Journal of Manufacturing Science and Technology*, Vol. 1 No. 4, pp. 237-246.

Nemeth, T., Ansari, F. and Sihn, W. (2019), "A maturity assessment procedure model for realizing knowledge-based maintenance strategies in smart manufacturing enterprises", *Procedia Manufacturing*, Vol. 39, pp. 645-654, doi: 10.1016/j.promfg.2020.01.439.

Nosalska, K., Piątek, Z.M., Mazurek, G. and Rządca, R. (2020), "Industry 4.0: coherent definition framework with technological and organizational interdependencies", *Journal of Manufacturing Technology Management*, Vol. 31 No. 5, pp. 837-862.

Oliveira, M.A. and Lopes, I. (2019), "Evaluation and improvement of maintenance management performance using a maturity model", *International Journal of Productivity and Performance Management*, Vol. 69 No. 3, pp. 559-581, doi: 10.1108/IJPPM-07-2018-0247.

Palys, T. (2008), "Purposive sampling", in Given, L.M. (Ed.), *The Sage Encyclopedia of Qualitative Research Methods*, Sage, Los Angeles, pp. 697-698.

Phaal, R. and Muller, G. (2009), "An architectural framework for roadmapping: towards visual strategy", *Technological Forecasting and Social Change*, Vol. 76 No. 1, pp. 39-49.

Phaal, R., Farrukh, C.J. and Probert, D.R. (2007), "Strategic roadmapping: a workshop-based approach for identifying and exploring strategic issues and opportunities", *Engineering Management Journal*, Vol. 19 No. 1, pp. 3-12.

Poór, P., Ženíšek, D. and Basl, J. (2019). "Radical change in machinery maintenance - a maturity model of maintenance using elements of industry 4.0", in Doucek, P., Chroust, G. and Oškrdal, V. (Eds), *IDIMT 2019: Innovation and Transformation in a Digital World - 27th Interdisciplinary Information Management Talks*, pp. 67-74.

Porter, M.E. (1996), "What is strategy?", *Harvard Business Review*, Vol. 74 No. 6, pp. 61-78.

Roy, R., Stark, R., Tracht, K., Takata, S. and Mori, M. (2016), "Continuous maintenance and the future – foundations and technological challenges", *CIRP Annals - Manufacturing Technology*, Vol. 65 No. 2, pp. 667-688.

Salonen, A. and Bengtsson, M. (2011), "The potential in strategic maintenance development", *Journal of Quality in Maintenance Engineering*, Vol. 17 No. 4, pp. 337-350.

Selcuk, S. (2017), "Predictive maintenance, its implementation and latest trends", *Proceedings of the Institution of Mechanical Engineers - Part B: Journal of Engineering Manufacture*, Vol. 231 No. 9, pp. 1670-1679, doi: 10.1177/0954405415601640.

Shyjith, K., Ilangkumaran, M. and Kumanan, S. (2008), "Multi-criteria decision-making approach to evaluate optimum maintenance strategy in textile industry", *Journal of Quality in Maintenance Engineering*, Vol. 14 No. 4, pp. 375-386, doi: 10.1108/13552510810909975.

Silvestri, L., Forcina, A., Introna, V., Santolamazza, A. and Cesarotti, V. (2020), "Maintenance transformation through Industry 4.0 technologies: a systematic literature review", *Computers in Industry*, Vol. 123, p. 103335, doi: 10.1016/j.compind.2020.103335.

Simões, J.M., Gomes, C.F. and Yasin, M.M. (2016), "Changing role of maintenance in business organisations: measurement versus strategic orientation", *International Journal of Production Research*, Vol. 54 No. 11, pp. 3329-3346, doi: 10.1080/00207543.2015.1106611.

Tan, Z., Li, J., Wu, Z., Zheng, J. and He, W. (2011), "An evaluation of maintenance strategy using risk based inspection", *Safety Science*, Vol. 49 No. 6, pp. 852-860, doi: 10.1016/j.ssci.2011.01.015.

Tsang, A.H. (1998), "A strategic approach to managing maintenance performance", *Journal of Quality in Maintenance Engineering*, Vol. 4 No. 2, pp. 1355-2511.

Veile, J.W., Kiel, D., Müller, J.M. and Voigt, K.-I. (2020), "Lessons learned from Industry 4.0 implementation in the German manufacturing industry", *Journal of Manufacturing Technology Management*, Vol. 31 No. 5, pp. 977-997, doi: 10.1108/jmtm-08-2018-0270.

Wang, L., Chu, J. and Wu, J. (2007), "Selection of optimum maintenance strategies based on a fuzzy analytic hierarchy process", *International Journal of Production Economics*, Vol. 107 No. 1, pp. 151-163, doi: 10.1016/j.ijpe.2006.08.005.

Whittington, R. (2004), "Strategy after modernism: recovering practice", *European Management Review*, Vol. 1 No. 1, pp. 62-68.

Xu, L.D., Xu, E.L. and Li, L. (2018), "Industry 4.0: state of the art and future trends", *International Journal of Production Research*, Vol. 56 No. 8, pp. 2941-2962.

Yin, R.K. (2018), *Case Study Research and Applications: Design and Methods*, SAGE publications, Los Angeles.

Ylipää, T., Skoogh, A., Bokrantz, J. and Gopalakrishnan, M. (2017), "Identification of maintenance improvement potential using OEE assessment", *International Journal of Productivity and Performance Management*, Vol. 66 No. 1, pp. 126-143.

About the authors

Camilla Lundgren is a PhD student at the Department of Industrial and Materials Science, Chalmers University of Technology. Her research focuses on implementation of smart maintenance, including aspects such as investments, strategy and leadership. Before starting her research career, she accumulated industrial experience as a production and logistics consultant at AFRY. Camilla Lundgren is the corresponding author and can be contacted at: camilla.lundgren@chalmers.se

Jon Bokrantz, PhD, is a Researcher at the Department of Industrial and Materials Science, Chalmers University of Technology. Jon has a background in Production Engineering, and his research focuses on maintenance in digitalized manufacturing.

Anders Skoogh is a Professor of Production Maintenance at Industrial and Materials Science, Chalmers University of Technology. He is a research group leader for Production Service and Maintenance Systems. Anders is also the director of Chalmers' master's program in Production Engineering and board member of the Think-Tank Sustainability Circle. Before starting his research career, he accumulated industrial experience from being a logistics developer at Volvo Cars.