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Implementing smart maintenance in the manufacturing industry

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Abstract

Purpose – The need for smart maintenance (SM) is increasing as the manufacturing industry digitalizes. To facilitate the transformation of maintenance in digitalized manufacturing, scholars have developed a strategy development process (SDP) for implementing SM. However, the SDP must be tested and evaluated, as manufacturing companies and industries need explicit guidance and empirical evidence on how to use it.

Design/methodology/approach – This study employed action research to facilitate collaboration between researchers and maintenance professionals in a large Swedish manufacturing company, testing and evaluating the SDP for SM implementation. The study was conducted in multiple phases over two years, focusing on the real-world implementation of key activities in an industrial setting.

Findings – Implementing SM in the manufacturing industry resulted in a refined SDP. The study revealed synergies between the implementation steps, from concept to practice. This refined process advances benchmarking (Activities 1.1–1.4), streamlines goal setting, prioritization and planning of key activities (Activities 2.1–4.1) and ensures authorized elevation and cross-functional communication (Activities 5.1–5.2) for digitalization of maintenance.

Practical implications – The theoretical implications refine the SDP and confirm the value of creating, acquiring and transferring knowledge within maintenance organizations, thereby facilitating SM implementation with empirical evidence. The practical implications offer recommendations for factory and maintenance management, providing explicit guidance to manufacturing companies in developing maintenance for digitalized manufacturing.

Originality/value – The refined SDP is an evolutionary process that requires continuous learning. This reinforces the focus on organizational development rather than solely technological transformation, i.e. becoming a learning organization when implementing SM.

Keywords Action research, Industry 4.0, Digital technologies, Manufacturing, Organizational change, Smart maintenance, Strategy

Paper type Research article

Quick value overview

Interesting because – Manufacturing companies and industries need explicit guidance and empirical evidence on transforming their maintenance organizations to meet the demands of digitalized maintenance. Digital technologies alone cannot achieve this, as human involvement remains essential and cannot be automated like production systems. Scholars have developed a strategy development process (SDP) to facilitate smart maintenance (SM) implementation, but it must be tested and evaluated to ensure it delivers value. This study addressed this need, resulting in a refined SDP for implementing SM in the manufacturing industry.

Theoretical value – The organizational perspective on maintenance digitalization has received growing attention, especially in SM. This study contributes by examining how SM can be implemented through testing and evaluation of the SDP. The theoretical implications confirm its value for maintenance organizations undergoing digital transformation. The SDP creates, acquires, and transfers knowledge as organizations digitalize, providing empirical evidence on how the transformation unfolds.

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Practical value – The refined SDP offers explicit guidance for factory and maintenance management in SM implementation. The study refines the process and provides recommendations for each step. For example, Step 1 (Activities 1.1–1.4) ensures participant selection, establishes SM knowledge and vision, employs the SM measurement instrument, and discusses results in small groups. The recommendation is to involve maintenance managers early, supported by factory management, to mobilize expertise. Implementing SM is an evolutionary process requiring a life-long commitment from factory and maintenance management teams.

1. Introduction

Digital technologies are rapidly transforming the manufacturing industry, with innovations becoming available at lower costs and at an ever-increasing pace (Benzell and Brynjolfsson, 2019). The adoption of digital technologies, such as the Internet of Things (IoT), Cyber-Physical-Systems (CPS), Big Data (BD), and Machine Learning (ML), is improving industrial efficiency and changing ways of working in manufacturing and maintenance (Vaidya *et al*., 2018; Alcácer and Cruz-Machado, 2019). Maintenance is particularly important in digitalized industries, as it not only drives productivity gains but also leverages data-intensive manufacturing to enable the practical application of Industry 4.0 (I4.0) (Gopalakrishnan *et al*., 2022), and, in the future, Industry 5.0 (I5.0) (Van Oudenhoven *et al*., 2023). Automation of knowledge-based decision support systems is shifting maintenance from descriptive to prescriptive policies, highlighting the key role of maintenance digitalization (Ansari *et al*., 2019; Silvestri *et al*., 2020). This digital transformation has grown research interest in maintenance, especially on achieving SM and shaping future industrial maintenance (Roda and Macchi, 2021; Compare *et al*., 2019). Such research is usually divided into two streams. One stream interprets it from a technological perspective (Ayvaz and Alpay, 2021), emphasizing digital technologies, such as IoT, CPS, BD, and ML, while the other interprets it from an organizational perspective (Bokrantz *et al*., 2020c), focusing on an organizational design for maintaining digitalized manufacturing. Digital technologies alone cannot digitalize maintenance organizations; human involvement is essential (Sgarbossa *et al*., 2020). Thus, realizing digitalized maintenance requires integrating social and human factors alongside technology (Beier *et al*., 2020; Schuh *et al*., 2015). Scholars therefore emphasize the need for further research on transforming maintenance organizations to meet digitalization demands (Osunsanmi *et al*., 2023; Lundgren *et al*., 2021; Hein-Pensel *et al*., 2023). To address this concern, Lundgren *et al*. (2021) proposed a SDP for SM implementation. However, the SDP needs to be tested and evaluated to ensure it delivers the value required by maintenance organizations undergoing digital transformation.

For this reason, the following study aims to test and evaluate the SDP for SM implementation in the manufacturing industry. A small research team of researchers and maintenance professionals at a large Swedish manufacturer collaborated over two years to implement SM using the SDP. Empirical data were continuously collected and analyzed through an action research design (Dickens and Watkins, 1999), including documents, workshops, interviews, and observations (Creswell, 2015). Theoretical implications refine the SDP and confirm its value, while practical implications offer recommendations for those implementing SM in the manufacturing industry. In the end, this study provides explicit guidance and empirical evidence for developing maintenance in digitalized manufacturing and contributes to the growing body of SM research.

The paper is organized as follows: Introduction elaborates on the need to test and evaluate the SDP for SM implementation; Related Literature outlines Industry 4.0, digitalized maintenance, and SM implementation; Methodology clarifies the action research design and data collection; Findings present empirical results by SDP steps; Discussion covers theoretical and practical implications, limitations, and future research; Conclusion summarizes the study.

2. Related literature

This section outlines related literature on testing and evaluating the SDP for SM implementation in the manufacturing industry, introducing I4.0, maintenance in digitalized manufacturing, and the implementation of SM.

2.1 Industry 4.0

In the industrial digital era, everything becomes digital – including business models, environments, production systems, machines, operators, products, and services (Alcácer and Cruz-Machado, 2019). I4.0, the fourth industrial revolution, drives digital transformation with a focus on sustainable economic, environmental, and social development (Ghobakhloo, 2020). Manufacturing aims to become "smart" by integrating CPS, which connect sub-systems with their environment through digital technologies to enhance flexibility, responsiveness, and efficiency (Monostori, 2014; Kusiak, 2018). Since I4.0's introduction (Kagermann *et al.*, 2011), manufacturing and maintenance have rapidly developed, supported by technology-oriented maturity models and concepts (Hein-Pensel *et al.*, 2023). I4.0 seeks to create interconnections, enable system integration, improve decision-making, provide technical support, and enhance human knowledge (Cañas *et al.*, 2021). This involves digital technologies, such as IoT, CPS, BD, and ML (Raja Santhi and Muthuswamy, 2023). However, scholars argue that digitalized manufacturing requires more than technology – it demands organizational development and a culture infused with digitalization (Neumann *et al.*, 2021; Sgarbossa *et al.*, 2020; Lundgren *et al.*, 2021). Existing maturity models and concepts primarily focus on technology, neglecting the crucial need for organizational redesign (Hein-Pensel *et al.*, 2023).

2.2 Maintenance in digitalized manufacturing

As digital technologies gain importance, the need to effectively manage and maintain assets in digitalized manufacturing increases. This is captured by Asset Management (AM), which goes beyond traditional maintenance by taking a holistic view of asset value, risk, and organizational adaptability (Amadi-Echendu, 2004; Lloyd, 2012, International Organization for Standardization, 2024). AM emphasizes designing assets for long lifespans and ensuring they can accommodate technological upgrades to maximize value for the company and its stakeholders.

Well-maintained manufacturing assets can improve energy efficiency and reduce consumption by up to 15% without extra costs or workforce (Polenghi *et al.*, 2025; Firdaus *et al.*, 2023), supporting sustainable economic, environmental, and social development (Ghobakhloo, 2020). In digitalized manufacturing, where flexibility, quality, and productivity are enhanced (Silvestri *et al.*, 2020), these benefits are expected to be even greater. Over the past 20 years, various maintenance policies have therefore emerged, reflecting the ongoing technological evolution in this field. These policies include, but are not limited to, predictive maintenance (Carnero, 2005), condition-based maintenance (Jardine *et al.*, 2006), intelligent maintenance (Moore and Starr, 2006), e-maintenance (Muller *et al.*, 2008), SM (Munzinger *et al.*, 2009), prognostics and health management (Lee *et al.*, 2014), data-driven maintenance (Herterich *et al.*, 2015), IoT-enabled maintenance (Roy *et al.*, 2016), Maintenance 4.0 (Kans *et al.*, 2016), i-maintenance (Strohmeier *et al.*, 2018), and prescriptive maintenance (Nunes *et al.*, 2023). This diversity of terminology and nuances has led to conceptual ambiguity (Shaffer *et al.*, 2016), creating multiple perspectives on maintenance digitalization. One interprets it from a technological perspective (Ayvaz and Alpay, 2021) while the other interprets it from an organizational perspective (Bokrantz *et al.*, 2020c). Over the past few years, the organizational perspective on maintenance digitalization has received particular attention (Roda and Macchi, 2021). SM is conceptualized by Bokrantz *et al.* (2020c) as an organizational design for managing maintenance in environments with pervasive digital technologies, consisting of four dimensions: data-driven decision-making, human capital resources, internal integration, and external integration. In short, data-driven decision-making enhances maintenance operations through smart data analytics; human capital resources focus on the necessary skills for digitalized maintenance; internal integration ensures collaboration within the company, while external integration emphasizes partnerships outside the company to harness innovation and leverage broader data sources. Consistent with Hein-Pensel *et al.* (2023) SM integrates organizational factors between "humans and machines" to support technological development in maintenance organizations.

2.3 Implementation of smart maintenance

Maintenance organizations need explicit guidance and empirical evidence on how to transform for digitalized maintenance (Osunsanmi *et al.*, 2023; Lundgren *et al.*, 2021; Hein-Pensel *et al.*, 2023). The digitalization of maintenance still faces resistance, including reluctance to adopt digital technologies and investment hesitancy (Bokrantz *et al.*, 2020b), unclear leadership and employee uncertainty (Lundgren *et al.*, 2022), as well as barriers related to cybersecurity regulation, IoT integration, and BD management (James *et al.*, 2023). Several maturity models and instruments exist, such as the Lean SM model (Schmiedbauer *et al.*, 2020), the SM instrument (Bokrantz *et al.*, 2020a) and the maintenance digital transformation framework (Saihi *et al.*, 2023). Since this study tests and evaluates the SDP for SM implementation, the SM instrument was used. It is a psychometric tool measuring the four SM dimensions and can assess, benchmark, and track SM in the manufacturing industry. For its development and validation, see Bokrantz *et al.* (2020a).

Lundgren *et al.* (2021) present an iterative six-step SDP for implementing SM: (Step 1) Benchmarking of the maintenance organization – using the SM instrument to assess the four dimensions, identify improvement needs, and engage employees; (Step 2) Setting clear goals – defining and communicating aligned clear goals; (Step 3) Establishing strategic priorities – managing interdependencies among dimensions to guide sequencing; (Step 4) Planning key activities – identifying and scheduling actions via workshops and roadmaps; (Step 5) Elevating implementation – executing activities while addressing cultural, technological, and leadership-related enablers and barriers; and (Step 6) Follow-up – using indicators to link outcomes to goals and sustain engagement.

In short, the SM instrument (Bokrantz *et al.*, 2020a; Bokrantz and Skoogh, 2023) identifies areas for improvement, while the SDP realizes them through iterative development steps. This study contributes to the growing body of SM research by examining how SM can be achieved and facilitated through the testing and evaluation of the SDP in the manufacturing industry.

3. Methodology

This section presents the action research design used to test and evaluate the SDP, including the empirical setting, data collection and analysis.

3.1 Research design

This study employed action research to test and evaluate the SDP for SM implementation (Lundgren *et al.*, 2021). Action research is a collaborative method for understanding and solving real problems through critical thinking (Ferrance, 2000). It involves observing, understanding, and changing situations while reflecting on actions to guide the research process (Dickens and Watkins, 1999). Because it is closely linked to practical problems, action research produces results directly applicable to industry and supports the integration of concepts into practice, benefiting both industry and academia (Ollila and Yström, 2020). Hence, action research was chosen as a suitable research methodology for testing and evaluating the SDP for SM implementation in a real-world industrial setting. Following Halldórsson and Aastrup (2003), who recommend new research methodologies, the study applies an action research design to test and evaluate the SDP for SM implementation in the manufacturing industry, thereby opening new perspectives for how researchers and maintenance professionals can work with maintenance digitalization.

Initially developed by Lewin (1946) to study intergroup relations in large organizations, action research is commonly described as comprising five phases: planning, acting, observing, reflecting, and reconceptualization (Dickens and Watkins, 1999). Action research starts with planning, identifying complex problems and designing actions. In the acting phase, actions are implemented and data collected. Observing, often concurrent with acting, gathers additional data to deepen understanding. Reflecting involves evaluating data to assess problem resolution and identify insights. Finally, reconceptualization applies lessons learned and decides whether to conclude or continue the research cycle.

Researchers collaborated with maintenance professionals in an industrial setting to test and evaluate the SDP for SM implementation using action research. Figure 1 shows the research design and how each SDP step was evaluated through the five phases of action research. Specifically, it illustrates how the first step of the SDP – benchmarking of the maintenance organization – was tested and evaluated. Note that Steps 1–4 were tested and evaluated using individual action research cycles, while Steps 5–6 were consolidated and followed up through interviews due to their industry-specific and time-intensive nature, which was beyond the study's scope.

3.2 Empirical setting

This study was conducted at a large Swedish manufacturing company, specifically in the pulp and paper industry, across multiple phases from spring 2022 to spring 2024. During the first six months of the study, work was conducted to initiate the SM implementation at the manufacturing company. At the end of the study, after 15 months, the SM implementation was followed up on, and the SDP was evaluated and later refined. In the meantime, several visits were made to the manufacturing company.

The pulp and paper industry served as a valuable setting to test and evaluate the SDP due to its strong focus on digitalized manufacturing and maintenance. The company sought explicit

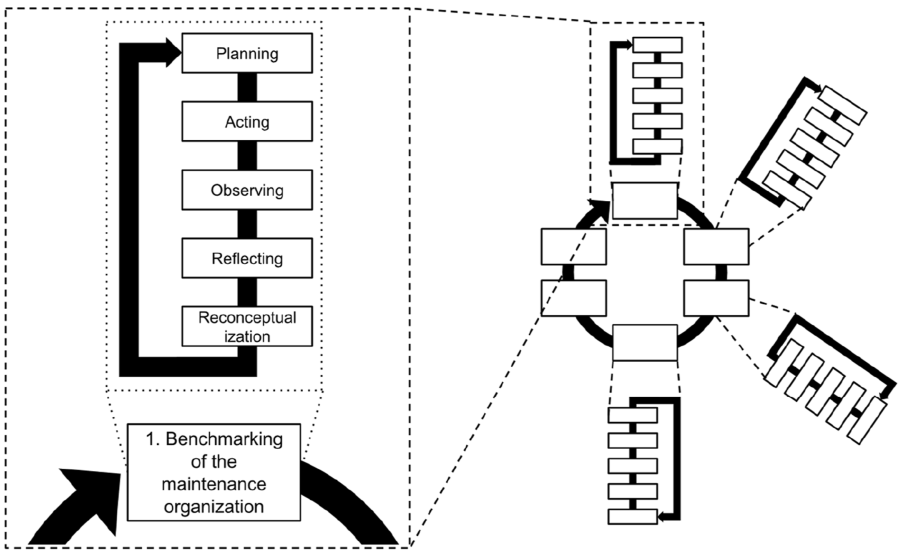

Figure 1. Action research was used to test and evaluate each step in the SDP for SM implementation.
Source(s): Authors' own work

guidance and empirical evidence to advance their maintenance digitalization. While the SDP by Lundgren *et al*. (2021) offered an initial approach, the company recognized the need for further support on how SM could be achieved and facilitated in their specific manufacturing context.

For this reason, a research team of seven individuals was formed to test and evaluate the SDP at one of the manufacturing company's operating pulp and paper mills. The team consisted of two researchers who joined the manufacturing company as relative insiders, granting them access to company resources and regular factory visits, as well as four maintenance engineers and one maintenance planner already working at the factory. These maintenance professionals worked in the central maintenance organization at the pulp and paper mill, with varied experience ranging from three to 25 years. In addition, two additional researchers supported the team as relative outsiders by contributing theoretical and empirical interpretations at regular intervals, helping to reduce bias in the analysis process. This research setup enabled authentic data collection and analysis in a real-world industrial setting, aiming to facilitate the implementation of SM by testing and evaluating the SDP in the manufacturing industry.

3.3 Data collection and analysis

Figure 2 visualizes the entire study's data collection and analysis process, including the timeline, for testing and evaluating the SDP for SM implementation. While the initial review focused on digitalized manufacturing and maintenance, the later one addressed maintenance engineering and organizational development. The empirical data generated from the research design, that is, from the cycles of action research, were looped back into the continuous literature review for the reconceptualization of the research design. This process led to conclusions that refined the SDP for SM implementation, facilitating the move from concept to practice.

Empirical data were collected at each step of the SDP at the manufacturing company and categorized into four groups; documents, workshops, interviews, and observations. First, the research team reviewed documents to understand the starting point of implementation.

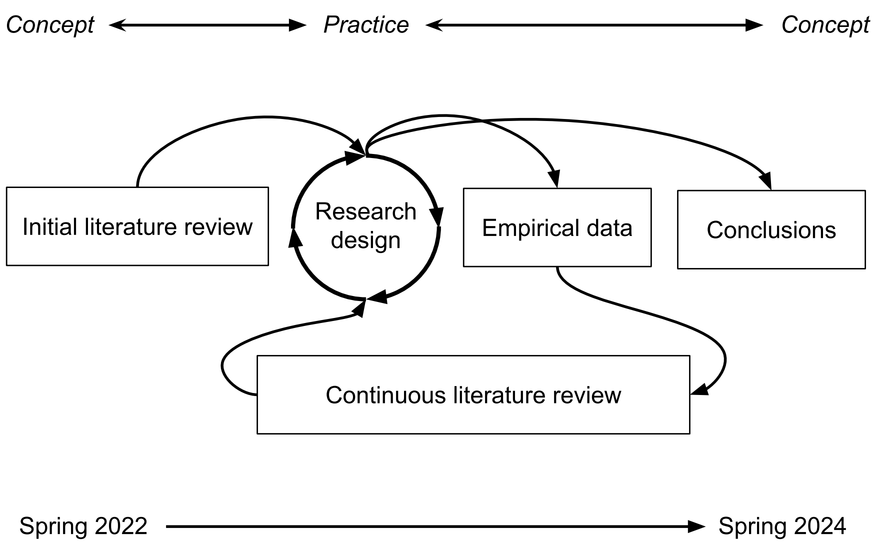

Figure 2. Data collection and analysis process, including the timeline, for testing and evaluating the SDP in SM implementation. **Source(s):** Authors' own work

Second, workshops were conducted with the research team to plan key activities. Here, maintenance professionals at different levels of the organization, including technicians, planners, engineers, managers, and directors, were invited depending on the type of key activity. Third, interviews were conducted after one year (before Step 5: Elevating implementation) and two years (after Step 6: Follow-up) to evaluate the SDP for SM implementation. Fourth, observations were made throughout the entire study, primarily by two researchers who joined the manufacturing company as relative insiders, providing them with unstructured insights on the perceived reality. Table 1 displays the phases of action research and examples of empirical data collected from each phase. Informed by the action research

Table 1. Data collection and examples of empirical data from each phase

Action research phase	Data collection	Empirical example
Planning. Outlined how (each step of) the SDP would be carried out, i.e. tested, in the field. This phase prepared how the SDP should be tested and evaluated, which can be described as "planning within planning"	Documents were reviewed to ensure alignment with the manufacturing company's current practices. Workshops with the research team were conducted to prepare new materials, and interviews with maintenance managers provided additional input	Documents included strategic plans and goal documents from the manufacturing company. Workshops prepared the SMART model and roadmapping activities. Semi-structured interviews provided checkpoints
Acting. Executed the planning phase, which focused on the "do's" of testing and evaluating the SDP, allowing both researchers and maintenance professionals to collaborate and integrate it into daily operations	Documents, workshops, and interviews were conducted at the manufacturing company to carry out the activities and collect data. The execution was led by the research team and involved the team itself, maintenance managers, and, at times, other professionals	Documents developed new templates for the manufacturing company. Workshops generated A3s, activity plans, and Gantt charts for each activity. Interviews validated the created materials
Observing. Monitored the SDP work to capture hidden insights, challenges, and outcomes in the acting phase. This phase focused on revealing changes and learning, helping the research team refine its understanding of how the SDP actually unfolded in practice	Observations were digitally recorded throughout the study, noting details such as actor, time, situation, and underlying sentiments that could influence documents, workshops, and interviews with the research team, maintenance managers, and other professionals	Observations in workshops captured different perspectives on goal-setting and the delayed effects on brainstorming key activities. Observations in interviews identified varying levels of basic knowledge in SM.
Reflecting. Analyzed the final SDP progression to determine whether actions from the acting and observing phases met the objectives set in the planning phase. Identified factors influencing the SDP guided improvements for the next action research cycle	Workshops, interviews and observations were used to evaluate findings and reflect on areas of improvement for the SDP. Findings were discussed with the research team when needed, and all findings were also compared with the related literature	Observations showed an interest from the research team in being more involved in goal-setting. Workshops concluded that working on goals simultaneously complicated the process and reduced clarity
Reconceptualization. Captured the most important findings from the reflecting phase to facilitate the SM implementation. Lessons learned came from all action research phases and provided explicit guidance on how to refine the SDP	Documents were compiled with the most important findings to refine the SDP. Interviews were conducted with the research team, maintenance managers, and other professionals to reach consensus	Documents consisted of lessons learned, discuss SM benchmarking results in small groups, provide support material when setting clear goals, and authorize people when planning key activities

Source(s): Authors' own work

guide, control questions were used to ensure that each phase met the criteria before moving to the next, see Appendix 1.

Furthermore, before elevating the planned key activities (Step 5), semi-structured interviews were conducted to consolidate the initial part of the implementation process. Informed by the first semi-structured interview guide, individual interviews with each member of the research team were conducted five months after project start (summer 2022) to evaluate the initial value of the SDP, see Appendix 2. After elevating the planned key activities (Step 5), another set of semi-structured interviews was conducted one year later (spring 2023) to follow up on the implementation process (Step 6). Informed by the second semi-structured interview guide, individual interviews were conducted again two years later (spring 2024) with the same participants to evaluate the final part of the implementation process and the final value of the SDP, see Appendix 3.

The empirical data collected from Steps 1–4 and Steps 5–6 followed a standardized analysis procedure inspired by (Creswell, 2015): (I) preparing the data by transcribing it, (II) exploring the data by reading the transcripts, (III) coding the transcripts into first-order codes based on the research guidelines, see Appendixes, (IV) categorizing these codes into second-order codes based on similarity, and (V) interpreting the categories and compare the findings with related literature. By doing so, comments and insights from documents, workshops, interviews, and observations were transformed into derived categories, consolidating first-order codes into second-order codes. For example, to consolidate the initial part of the SM implementation and identify challenges with the SDP, audio files from semi-structured interviews with the research team were transcribed, read, and coded according to the interview guide. This structured the responses into first-order codes for each question and interviewee, which were placed in a digital workspace. Researchers then analyzed the responses, and second-order codes emerged based on similarities between first-order codes. Both researchers agreed on each of the derived categories. In this way, the derived categories summarized lessons learned in terms of perceptions, challenges, significance, and improvements, which were used to evaluate the SDP for SM implementation, ultimately resulting in a refined SDP.

4. Findings

This section presents all findings from the action research cycles, consolidation and follow-up of the SM implementation. The results are presented in chronological order according to the SDP. Note that Steps 1–4 of the SDP were conducted as individual action research cycles.

4.1 Findings from the strategy development process

4.1.1 Step 1: benchmarking of the maintenance organization. **Planning.** The research team used the instrument to measure the four dimensions of SM. Ten participants from the maintenance organization were selected, including the director, four managers, four engineers, and one planner, to complete the survey. The results were then presented and discussed in a focus group meeting with the entire maintenance team and additional representatives to identify areas for improvement and enhance engagement with SM.

Acting. Participants were invited via email to complete the survey, followed by a digital workshop one week later. The results were shared in advance to allow reflection. During the workshop, researchers presented their results, encouraged discussion on potential improvements, and documented the main topics and questions. For example, one of the improvements was the selection of KPIs, where a participant said, “*We need to revise them, not just remove or create new ones*.” Topics covered by the workshop also included the definition of SM and its dimensions, the number of respondents to the instrument, the process of generating SM instrument results, and examples of SM in daily operations.

Observing. Of the ten invited to complete the survey, six participants responded. During the workshop, the participants were involved to varying degrees. One of the participants said:

"*Is there any value in letting employees in the organization respond to a survey?*" Furthermore, those who contributed to the discussion focused on terminology rather than the survey results, indicating varying levels of basic knowledge of SM. For example, one of the participants asked, "*What is data-driven decision-making?*"

Reflecting. The researchers observed deviations from the planning phase, as the workshop required a basic knowledge of SM as a concept to identify areas for improvement, which seemed to be lacking among the participants. One participant commented on the varying levels of basic knowledge of SM, *"It was as if you thought we had come further in terms of SM, when in reality it would have been better if we had met halfway."* Reflecting on the workshop, the researchers identified several factors contributing to the deviation. First, the expectations of the researchers and participants differed, with most expecting a presentation rather than a discussion of the results. For example, the maintenance director stated, "*It was a great presentation and right on time."* Second, the workshop was scheduled on short notice, limiting preparation time, and the digital format was not ideal; future discussions should be held in person. Third, the group composition was suboptimal, as managers and employees who rarely interacted were brought together, hindering discussion. As a result, the benchmarking process took a different direction than planned, primarily due to participants' varying levels of basic knowledge of SM. The discussion mainly focused on definitions and interpretations, highlighting a lack of a clear vision of SM.

Reconceptualization. The findings from the reconceptualization of Step 1 are presented below.

(1) **Smaller groups:** Discussion meetings should be held in small groups within each department, as smaller groups facilitate open discussion and minimize hierarchical barriers.

(2) **Choice of environment:** The format and environment of the meeting are crucial. Discussion meetings should not be digital or in settings that hinder open discussion of benchmarking results.

(3) **Sufficient understanding:** A basic knowledge of SM is essential for identifying areas for improvement that are relevant to the organization.

(4) **Shared vision:** Without a clear vision of SM, it is difficult to reach a consensus on necessary improvements. The maintenance organization needs to articulate why SM should be implemented.

4.1.2 Step 2 & step 3: setting clear goals and setting strategic priorities. **Planning**. The research team divided the identified problems into four activities. The first activity was to schedule a workshop with the maintenance management team, the usual body responsible for goal setting. The second activity was to inform and train the team on setting SM goals using the SMART model, which makes goals specific, measurable, attainable, realistic, and time-bound. The third activity was to conduct the goal-setting workshop, during which goals were generated and prioritized using the benchmarking results from the survey. The fourth and final activity was to communicate the goals to the maintenance organization. Before the acting phase, two semi-structured interviews were conducted with the maintenance director and one of the maintenance managers to review the planning phase. The manager suggested removing the training on setting goals, stating, "*These are experienced leaders, and conducting a training session on how to formulate goals will probably do more harm than good*." There was concern that this might create resistance and hinder commitment. The maintenance manager also recommended providing support materials for the workshop to save time. This support material can be described as a summary of information for decision-making. As a result, the training was replaced with a workshop for the research team to generate suggestions for areas of improvement in SM.

Acting. The first activity was a workshop with the research team to generate suggestions for SM improvement areas based on the benchmarking results from Step 1. These suggestions were then presented to the management team at the goal-setting workshop. During the workshop, the researchers collaborated with the maintenance managers to transform the identified areas for improvement into SM goals. One maintenance manager suggested returning to the research team since "*they had better knowledge of SM than the management team*" to continue refining the improvement areas into goal suggestions. A maintenance manager later reviewed these suggestions for quality before being presented to the management team in a follow-up meeting. At the meeting, the goals were revised, strategic priorities were set, and a timeline was created to visualize the goals and aid internal communication. The goals were prioritized based on their interrelation, with some requiring completion before others, making the prioritization process relatively straightforward.

Observing. There were differing perspectives on the goal-setting process within the maintenance organization. The research team believed that "*goals are set at the top by the managers and then trickled down the organization*". In contrast, the management team thought that "*employees within the organization could easily suggest goals*". The management team also found it challenging to set clear goals for SM, despite adjustments made to the procedure to accommodate their needs. The lack of time was mainly due to their unfamiliarity with SM, coupled with a high interest in learning more. Additionally, the goal-setting workshop took place early in the implementation process, leading to time-consuming discussions. As a result, it became evident that the support material was not well adapted to the management team's current SM knowledge, necessitating additional workshops. One of the maintenance managers said, "*We expected updates on what had been done, while you expected a discussion and a working meeting.*"

Reflecting. The time required to set goals for SM was underestimated by the research team, maintenance director, and managers, leading to a workshop designed on incorrect premises. During the workshop, it became clear that the goal-setting process occurred too early in the SM implementation. The management team had not yet had the chance to reflect on SM and was unclear about its concept. As a result, the support material was insufficient, favoring a general, educational discussion. This led to intense discussions and employee engagement, which were intended for earlier steps of the SDP. For example, the maintenance director said at one point, "*Our work and development processes will be slower than research processes.*" The acting phase highlighted that the management team needs a certain level of knowledge of SM to set goals. Therefore, more precise support material is required for low knowledge levels. To address this, sufficient time should be allocated to discuss areas for improvement, such as benchmarking, before transforming them into clear goals. When the research team formulated goal suggestions, as recommended by the management team, they observed a strong commitment to goal-setting, which helped engage employees and brought goals closer to daily operations. The maintenance director reflected, "*One idea is for more knowledgeable individuals in SM to lead these meetings to oversee the discussion.*" However, management approval is always necessary to avoid authorization issues. Since the research team already had a certain level of knowledge about SM, no precise support material was needed. The group also expressed interest in being more involved in goal-setting: "*it was inspiring and really reflective to generate these goals*", particularly for goals related to "*everyday activities*", but found organizational goals harder to relate to and formulate. Thus, maintenance managers and employees must collaborate to find SM goals at all levels of the organization. Time, once again, was a limiting factor in goal formulation, so sufficient time is crucial to set clear SM goals.

Reconceptualization. The lessons learned from the reconceptualization of Step 2 and Step 3 are presented below.

(1) **Utilize workshops:** While challenging to organize, workshops are valuable for teaching employees about SM implementation.

(2) **Provide support materials:** If the management team lacks familiarity with SM, tailored support materials are beneficial, varying in precision based on their level of basic knowledge of SM.

(3) **Use smaller groups:** Goal suggestions can be formulated in smaller groups alongside the management team; however, these suggestions must be approved by the management team to avoid authorization issues. Combining expertise from various levels improves the goal-setting process for SM.

4.1.3 Step 4: planning key activities. **Planning.** The primary objective of Step 4 was to plan key activities aligned with the SM goals and visualize them in a roadmap. The research team divided the task into three activities: a brainstorming workshop to generate key activities, a road mapping workshop to visualize them, and a focus group to compile an activity plan outlining what, how, who, and when the key activities should be performed. Given their familiarity with Steps 2 and 3, the research team was selected to carry out Step 4.

Acting. In the first workshop, the research team generated activities needed to achieve each SM goal. These were then visualized in a road mapping workshop, which broke down each goal into specific activities. Finally, a focus group validated the roadmaps and created a detailed activity plan with responsibilities and deadlines.

Observing. Although the management team had approved the SM goals, the brainstorming workshops lacked formal authorization, so checkpoints were added to ensure direct management approval. One research team member said, *"Technical improvements are easier to plan, while strategic ones need more involvement from management."* New key activities were also brainstormed during road mapping workshop, which was unplanned. Another participant noted, *"It is much better to see what is needed when you have this overview."* During the focus group, the research team expressed appreciation for Step 4 and eagerness for Step 5, reflecting on the activity plans and seeking more responsibility for the SM implementation.

Reflecting. During the workshops, the research team hesitated about their authority to decide how and by whom key activities should be carried out, expressing concern about assigning responsibilities. One member stated, "*If we do not assign appropriate responsibilities, there is a huge risk of activities not being completed on time.*" Visualizing activities in roadmaps helped create consensus, and the group agreed that road mapping was crucial for Step 4. However, working on all goals simultaneously complicated the process, and one member suggested, "*It would have been better to work with one goal at a time.*" Despite these challenges, Step 4 increased the group's engagement, as they saw their theoretical work taking action, with one member reflecting, "*The more theoretical work from Steps 1, 2, and 3 is now taken into action, which is exciting*."

Reconceptualization. The lessons learned from the reconceptualization of Step 4 are presented below.

(1) **Ensure authorization**: To make Step 4 efficient and avoid unnecessary checkpoints, ensure that those planning the key activities have proper authorization.

(2) **Involve the right people**: Engage those responsible for executing the activities in the planning process to enhance employee engagement and involvement.

(3) **Use roadmaps**: Visualizing key activities in roadmaps is crucial for clarity and understanding, so road mapping workshops should not be skipped.

(4) **Plan goals separately**: Planning each SM goal from start to finish helps reduce confusion and clarify responsibilities.

4.1.4 Step 5: elevating implementation. Before the planned key activities could be elevated (Step 5), semi-structured interviews were conducted to consolidate the initial part of the SM implementation (Steps 1–4). The consolidation process included 167 comments and insights from first-order codes, from which 14 categories were derived as second-order codes, evaluating the SDP before elevating the SM implementation, and is visualized in Figure 3. The representation of first-order codes is presented in parentheses alongside each consolidation.

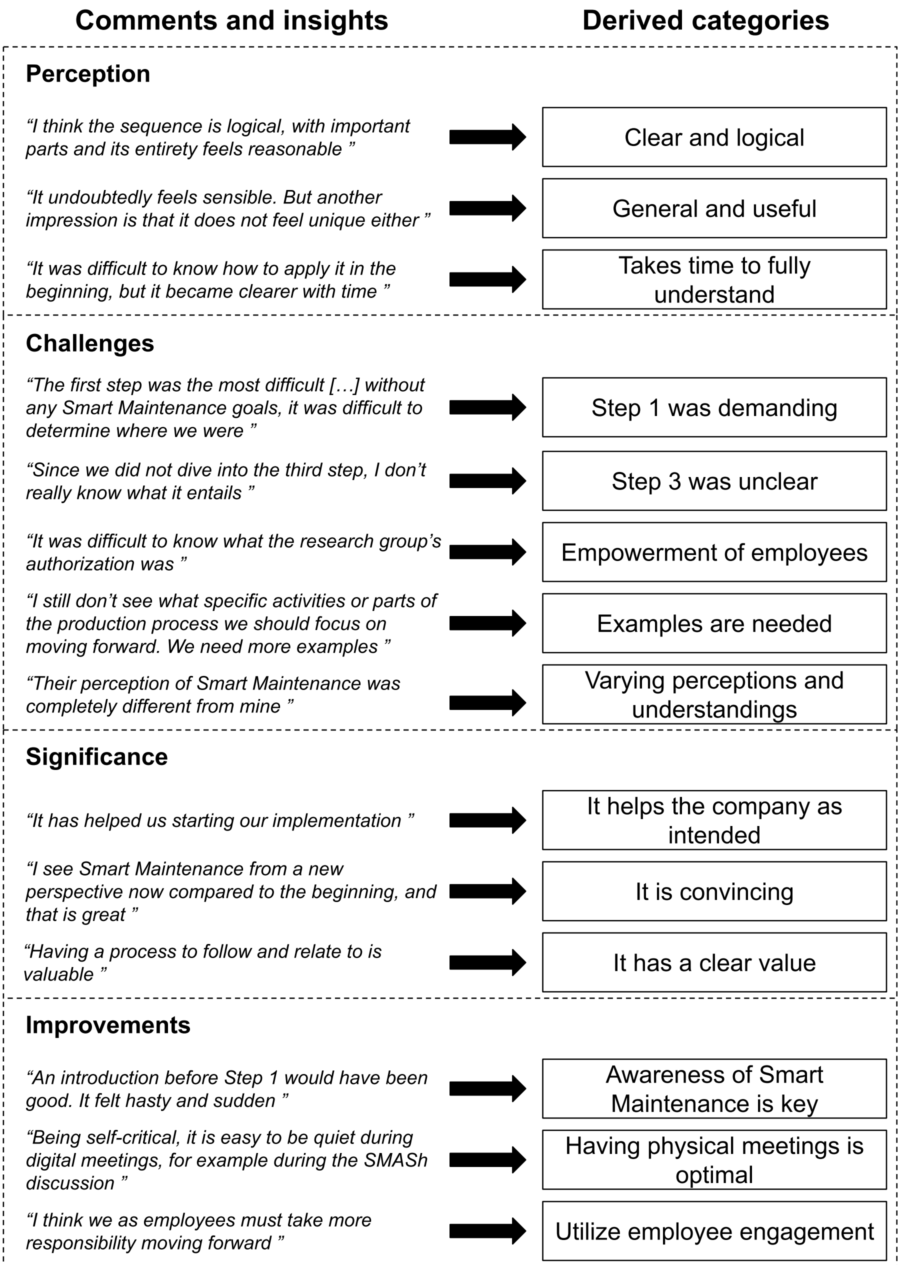

Figure 3. Derived categories from the consolidation process of Steps 1–4. **Source(s):** Authors' own work

Consolidation: The derived categories from the consolidation of Steps 1–4 are presented below.

(1) **Perception (25%)**: The SDP was perceived as "*clear and logical*" and "*general and useful*". It had an easy-to-understand structure and was perceived as meaningful. However, some steps were time-consuming to understand, and a gap existed between concept and practice, making it challenging to define goals and keep discussions focused.

(2) **Challenges (32%)**: Step 1 was overwhelming and occurred too early. Step 3 was unclear due to its limited inclusion in the research design. Other challenges included authorization issues, the need for education to bridge the concept-practice gap, and the requirement for increased employee involvement to enhance engagement.

(3) **Significance (24%)**: All participants agreed that the process demonstrated clear value in implementing SM at the manufacturing company. Belief in its value grew as the implementation progressed, and the research team felt it should continue beyond the study.

(4) **Improvements (19%)**: Step 1 should be revised, especially the survey, which should involve more people and include pre-introductions to SM. Physical meetings should be prioritized for better discussions. Additionally, the research team should gradually take on more responsibility as the process unfolds, preparing them to drive the implementation forward.

4.1.5 Step 6: follow-up. After the planned key activities had been elevated (Step 5), semi-structured interviews were conducted again to follow up on the final part of the SM implementation (Step 6). The follow-up process included 131 comments and insights from first-order codes, from which 13 categories were derived as second-order codes, evaluating the SDP after implementing the SM. These categories are visualized in Figure 4. The representation of first-order codes is presented in parentheses alongside each consolidation. The follow-up process also includes a qualitative description to improve transparency regarding the implementation's elevation.

The research team remained committed to the implementation of SM. Monthly meetings fostered cross-functional collaboration and improved the basic knowledge of SM. One of the research team participants said, "*Before, I thought SM was all about sensors and devices, but it is really about working smarter, which relates to my everyday work. It is not 'smart' like in smartphones.*" The terminology of SM was used among those involved, while externally, the key activities were more commonly referred to as maintenance improvements. The implementation gained momentum after three months as it aligned with other ongoing projects at the company, such as production improvements and digitalization initiatives. For example, one of the maintenance managers stated, "*SM should not exist as a separate world.*" These projects shared similar goals, including improving the reliability and efficiency of maintenance within the factory. However, several projects slowed down when the maintenance director left the organization, emphasizing the reliance on a limited number of individuals to drive the SM implementation forward. Without official prioritization of resources, the implementation struggled. After six months, some key activities were integrated into another improvement project led by factory management. There was still a commitment to implementing SM, but the term was abandoned to avoid introducing another improvement concept. One said, "*It is probably better to just work on SM without saying it.*" The main improvement focused on building a fundamental understanding of organizational development rather than solely technological transformation. However, the SM implementation faced resistance at the top of the organization, especially in coordinating the factory and maintenance management teams. Despite the manufacturing company's strong interest in research and development for digitalized maintenance, the implementation still

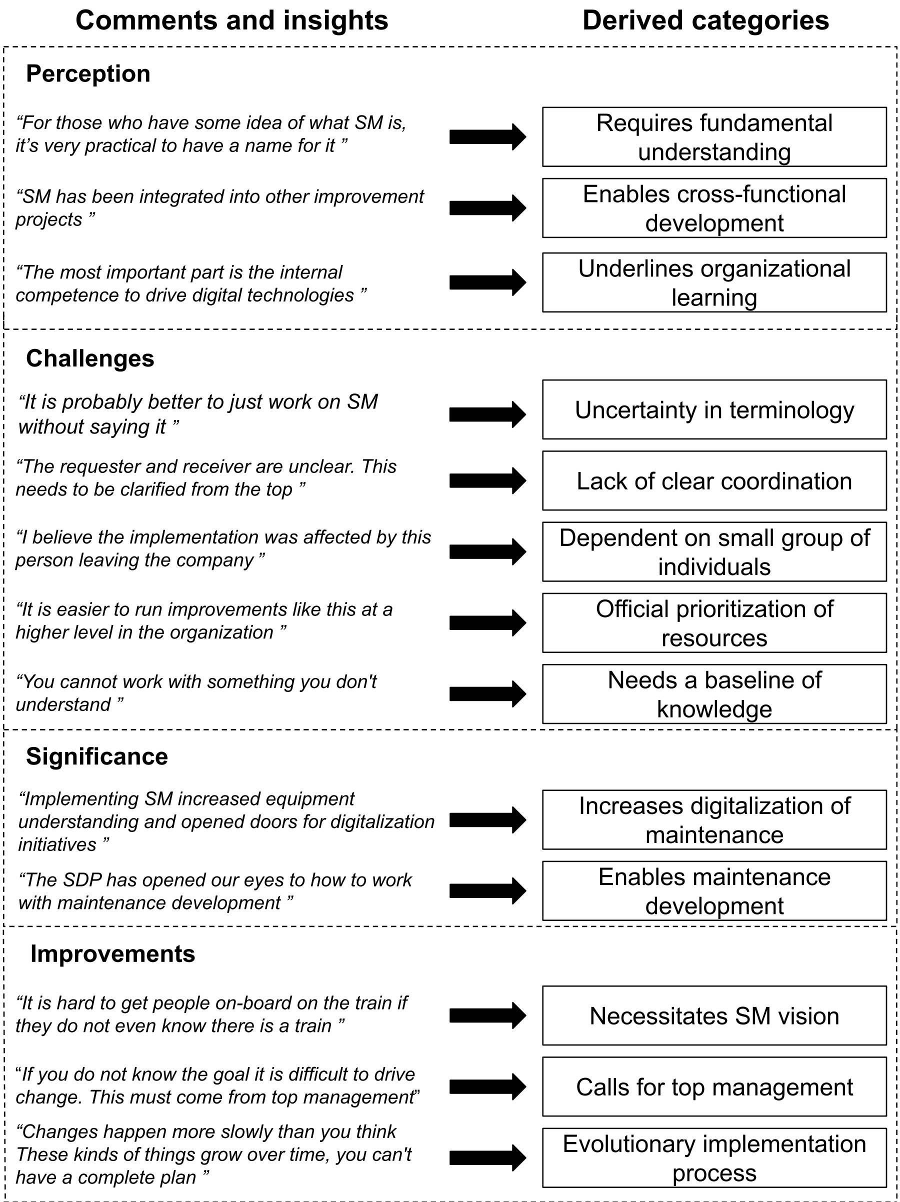

Figure 4. Derived categories from the follow-up process of Steps 5–6. **Source(s):** Authors' own work

relied too heavily on a small group within the maintenance organization. The lack of precise coordination between the management teams made it difficult to clarify the purpose of the planned key activities and to maintain the pace of the implementation. As one member of the research team stated, "*It is difficult to drive change if you do not know the goal. This must come from top management.*"

Follow-up: The derived categories from the follow-up of Steps 5–6 are presented below.

(1) **Perception (27%):** The research team remained committed to implementing SM, enabling cross-functional collaboration and organizational learning across projects. Internally, participants adopted SM terminology, while externally, SM was often framed as general maintenance improvements, as basic knowledge of SM was needed.

(2) **Challenges (36%):** The implementation was hindered by the departure of the maintenance director, underscoring the organization's dependence on a few key individuals. Without formal resource prioritization, the pace of implementation decelerated. Coordination between the factory and maintenance management teams was hindered by different baselines of knowledge, creating certain resistance to the SM implementation.

(3) **Significance (13%):** The SM implementation was gradually integrated into other improvement projects, thereby increasing the digitalization awareness of maintenance. The SDP enabled development beyond technology, indicating organizational learning in maintenance organizations.

(4) **Improvements (24%):** Coordination and leadership are essential for implementing SM. A shared vision is needed to align teams and prevent harmful coordination. Furthermore, the implementation must be allowed to take its time, indicating an evolutionary process.

5. Discussion

This section discusses the findings from the action research cycles, consolidation, and follow-up of the SM implementation, including the theoretical implications of the refined SDP, practical implications for implementing SM in the manufacturing industry, as well as its limitations and directions for future research.

5.1 Theoretical implications of the refined SDP

Implementing SM in the manufacturing industry refined the SDP, as detailed in Figure 5. The refinements are highlighted in bold. The theoretical implications confirm its value for maintenance organizations implementing SM. A real-world industrial setting using an action research design (Dickens and Watkins, 1999) revealed synergies between the implementation steps, thereby enhancing the initially proposed SDP (Lundgren *et al*., 2021). The consolidation and follow-up confirmed that the process effectively creates, acquires, and transfers knowledge within maintenance organizations, adding confirmed value when implementing SM in the manufacturing industry. This reduces conceptual ambiguity (Shaffer *et al*., 2016). The refined SDP provides explicit guidance and empirical evidence on how their digital transformation should unfold, thereby aligning with statements from Hein-Pensel *et al*. (2023), Osunsanmi *et al*. (2023) and Lundgren *et al*. (2021).

5.1.1 Step 1: benchmarking of the maintenance organization. Step 1 involves selecting participants for the SM instrument (Activity 1.1), ensuring diverse representation, and fostering engagement by involving related departments, such as production and automation, to identify areas for improvement. Participants should possess a basic knowledge of SM and share its vision; otherwise, Activity 1.2 provides an introduction or training on SM and its four dimensions. In Activity 1.3, participants use the SM instrument, followed by Activity 1.4, where results are discussed in smaller, relevant groups during physical meetings.

5.1.2 Step 2 & step 3: setting clear goals and strategic priorities. Building on improvement areas from Step 1, Steps 2 and 3 are merged, starting with Activity 2.1 to generate SM goal suggestions in continued small groups. Combining Activities 1.4 and 2.1 can streamline the process. The goal suggestions are then refined in workshops (Activity 2.2) to set clear and

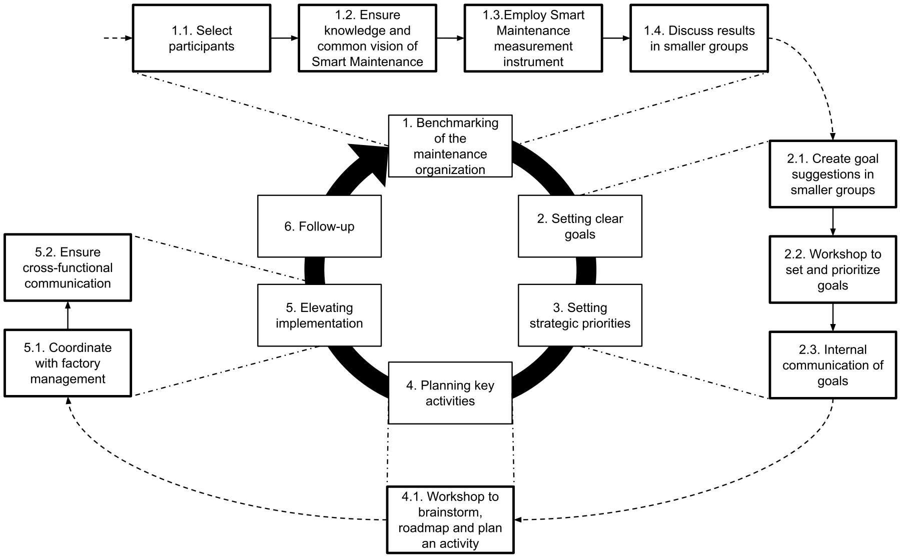

Figure 5. The refined SDP for SM implementation. **Source(s):** Authors' own work

prioritize strategic goals. Finally, schematic timelines (Activity 2.3) support internal communication and engage the broader organization beyond the maintenance function.

5.1.3 Step 4: planning key activities. In Step 4, SM goals are used to plan and schedule key activities. In Activity 4.1, a workshop identifies key activities, creates roadmaps, and generates activity plans that outline responsibilities, accountabilities, and deadlines. Involving those who implement the key activities promotes engagement. The workshop should focus on one goal at a time to improve clarity and efficiency, and it should have sufficient authority to finalize key activities without requiring additional approval from maintenance management.

5.1.4 Step 5: elevating implementation. Step 5 initiates Activity 5.1, where each key activity is coordinated with factory management to enhance implementation. Hence, cross-functional communication (Activity 5.2) is ensured with related departments to support centralized and decentralized information sharing when elevating the key activities.

5.1.5 Step 6: follow-up. Finally, Step 6 follows up on the results of each key activity to continuously provide feedback to the SDP for SM implementation. Step 6, therefore, does not need to be refined; instead, it should be tailored to the manufacturing company's policy for following up on implementations.

The refined SDP provides explicit guidance and confirms the value of implementing SM in the manufacturing industry. It advances benchmarking (Activities 1.1–1.4), streamlines goal setting, prioritization, and planning of key activities (Activities 2.1–4.1), and ensures authorized elevation and cross-functional communication (Activities 5.1–5.2). This supports knowledge creation, acquisition, and transformation within the maintenance organization, facilitating the implementation of SM in the manufacturing industry.

5.2 Practical implications for implementing SM in the manufacturing industry

Recommendations from each step of the SDP provide explicit guidance for directors, managers, engineers, and technicians across the maintenance function and beyond. The derived recommendations are: (Step 1) – Benchmarking of the maintenance organization: involve maintenance managers early, supported by factory management, to mobilize expertise for the implementation of SM; (Step 2) – Setting clear goals: define goals collaboratively, decentralization supports true problem-solving, while centralization ensures its coordination;

(Step 3) – Establishing strategic priorities: align priorities with production needs and long-term maintenance goals; let maintenance engineers define requirements; (Step 4) – Planning key activities: adjust key activities as needed and manage their resources alongside daily operations; (Step 5) – Elevating implementation: ensure shared understanding of key activities across departments; maintenance managers should address barriers and foster acceptance of change; (Step 6) – Follow-up: maintain momentum through continuous learning and clear accountability for each key activity. Implementing SM in manufacturing is an evolutionary process requiring lifelong commitment from both factory and maintenance management, emphasizing organizational development over technology alone (Bokrantz and Skoogh, 2023). These recommendations provide explicit guidance and empirical evidence for maintenance organizations undergoing digital transformation.

5.3 Limitations and future research

This study tested, evaluated, and finally refined the SDP for SM implementation in the pulp and paper industry. While offering valuable insights for maintenance organizations in digital transformation, the findings may not fully represent all manufacturing contexts. Future research should explore the SDP across diverse industries, including small and large firms, and greenfield and brownfield factories. Since this study focused on a large brownfield factory, further research in smaller, greenfield settings – such as new battery gigafactories – is of high interest to advance SM across the manufacturing industry.

Furthermore, the study focused solely on the SDP, excluding proprietary outcomes such as models, strategies, and algorithms from the company. To better understand real-world SM implementation, future research should examine case studies of key activities, demonstrating how various maintenance digitalization projects are addressed during SM implementation.

Likewise, there are several synergies between SM and AM, both aiming to develop the future maintenance management of industrial assets. As the strategic AM plan is central to AM, the SDP could serve as a practical tool within it to facilitate SM implementation. Future research should examine these synergies and how integrating the SDP into the strategic AM plan can increase value creation in digitalized manufacturing.

Finally, action research as a methodology presents both opportunities and limitations. While its results are directly applicable to practice, it also limits generalizability across other types of manufacturing industries. To that end, future research is encouraged not only to apply action research but also to utilize complementary methodologies to test further and evaluate the refined SDP.

6. Conclusion

Digital technologies are transforming industrial manufacturing and maintenance. To facilitate the transformation of maintenance in digitalized manufacturing, scholars have developed a SDP for implementing SM in the manufacturing industry. However, the SDP must be tested and evaluated, as manufacturing companies and industries need explicit guidance and empirical evidence on how to use it. For this reason, this study uses action research in a large Swedish manufacturer to test and evaluate the SDP. Theoretical implications refine the SDP, confirming its value in creating, acquiring, and transferring knowledge within maintenance organizations, thereby facilitating SM implementation. This is empirical evidence that contributes to the growing body of SM research. Practical implications provide explicit guidance for maintenance organizations undergoing a digital transformation. Recommendation reinforces the focus on organizational development rather than solely technological transformation, i.e. being a learning organization. Finally, four avenues for future research are proposed to further develop SM implementation in the manufacturing industry.

Declaration of AI use in writing

Parts of this paper were proofread using ChatGPT 5.0 to identify grammatical issues and improve readability. The authors manually evaluated all suggestions to ensure the intended tone and meaning were preserved and take full responsibility for the final content.

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Appendix 1

Table A1. Action research guideline

Planning	Acting	Observing	Reflecting	Reconceptualization
Identify the problem in its context	*Execute planned actions*	*Collect more data*	*Evaluate the execution*	*Capture the learnings*
Consider the following				
What is the problem?	Check the progress	Has anything changed?	What did I expect to happen?	Is the problem solved?
How does the problem affect the organization?	Collect the information	Take the opportunity to learn	What actually happened?	Can we move on, or do we have to start over and refine the problem?
Who should be included in the action research team?	Check the implementation		Why did it happen?	
How much time is needed?			What is the next step?	
Other perspectives of the problem?				
What is the goal?				
Any other people or resources that need to be involved?				
Are there any obstacles?				
Avoid non-value-adding-work!				
Control questions				
How do we get there?			Are the milestones and goals fulfilled?	How should the manufacturing company execute the step themselves?
Overall plan?				
What is the next step?				
Do everyone agree?				

Appendix 2

Table A2. First semi-structured interview guide

Number	Questions
1	What is your general opinion about the strategy development process for smart maintenance implementation?
2	What are the challenges with the strategy development process for smart maintenance implementation? Is something missing?
3	Do you think that the strategy development process for smart maintenance implementation has helped the organization accelerate their development journey towards smart maintenance?
4	Do you see any value in continuing to use the strategy development process for smart maintenance implementation?
5	How do you think our action research method has worked out?
6	What would you have done differently if this thesis were repeated?
7	Do you have another question or thought that you want to share?

Appendix 3

Table A3. Second semi-structured interview guide

Number	Questions
1	What challenges have you encountered during the implementation?
2	What positive changes have you observed since the implementation began?
3	Are there any areas where the implementation has been less successful?
4	Are there any adjustments or improvements that need to be made in the future to enhance the implementation?
5	What lessons have you learned from this implementation that could be useful for future projects?

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