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# Managerial practices shaping the transformation towards artificial intelligence-enabled product–service systems

Marko Kohtamäki [a,*], Thomas Brekke [b], Rimsha Naeem [c], David Sjödin [d], Vinit Parida [d]

[a] University of Vaasa, School of Management /, Luleå University of Technology, Entrepreneurship and Innovation, PO Box 700, FI-65101, Vaasa, Finland
[b] University of Southeastern Norway, School of Business, Department of Economic, History and Social Sciences, Norway
[c] University of Vaasa, School of Management, Finland
[d] Luleå University of Technology, Entrepreneurship & Innovation, University of South Eastern Norway, USN Business School, Norway

A B S T R A C T

This study explores the management of the emergence of artificial intelligence (AI)-enabled product–service systems (PSS) that facilitate a manufacturer's transition toward autonomous solutions. We use a case study involving a leading manufacturer actively developing autonomous and integrated solutions while incorporating AI into product–service systems (PSS) from 2015 to 2022. The study contributes to the digital servitization literature in two ways. First, the study merges AI into product–service systems through a multi-layered path model, which includes layers such as AI-enabled PSS, AI-related PSS technologies, and AI-related PSS ecosystem partnerships. Second, the study identifies managerial practices of strategizing, evangelizing, and routinizing to create AI-enabled PSS, providing guidance for managers planning to merge AI into their product–service systems. The study outlines a research agenda for future AI-enabled PSS. Additionally, it gives managers a framework to understand how to pursue the transition journey.

## 1. Introduction

Manufacturers, particularly those producing various vehicle types, are developing smart autonomous solutions (Thomson et al., 2022; Tsvetkova et al., 2021). This shift is often referred to as an advanced form of digital servitization[1] (Bustinza et al., 2018; Cenamor et al., 2017; Lerch and Gotsch, 2015). The combination of digitalization and servitization has significantly influenced innovation in manufacturing (Hsuan et al., 2021; Schroeder et al., 2020), enabling higher firm performance in revenues and profits (Kohtamäki et al., 2020a,b). This is particularly apparent when service investments have been significant enough to really move the company toward advanced services (Kastalli and Van Looy, 2013). This move necessitates development of new technologies (e.g. AI, data platforms), innovation in product–service offerings (e.g. autonomous solutions) and digital business models (Buhalis et al., 2019; Burström et al., 2021; Kohtamäki et al., 2024). In addition, effective ecosystem management capabilities – such as orchestration, integration, and learning – are essential (Iansiti and Lakhani, 2020). AI-enabled product–service systems (AI-enabled PSS) have shown great promise in co-creating customer value and generating increased financial returns for manufacturers. However, developing these AI-enabled PSS is complex, and many manufacturing companies still struggle to monetize their digital offerings (Linde et al., 2021; Sjödin et al., 2024).

In recent years, scholars have begun to employ the concept of digital servitization to emphasize the growing significance of digitalization in manufacturing firms and the importance of focusing on the digitalization of services, product–service systems, business models, and value system architectures. Yet, there are still important knowledge gap on the transformation towards AI-enabled PSS. First, there is a need for *further understanding the transformation pathways towards AI-enabled PSS*. Indeed, artificial intelligence encompasses a set of emerging technologies that have developed over time and are rapidly advancing in various industries, which make firm-level implementation and transformation processes particularly interesting. Research on AI in general has grown rapidly (Wamba et al., 2021), and the role of AI in servitization and product–service systems is starting to be explored (Naeem et al., 2024; Sjödin et al., 2021), with an increasing number of studies focusing on

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* Corresponding author.

*E-mail addresses:* marko.kohtamaki@uwasa.fi (M. Kohtamäki), thomas.brekke@usn.no (T. Brekke), rimsha.naeem@uwasa.fi (R. Naeem), david.sjodin@ltu.se (D. Sjödin), vinit-parida@ltu.se (V. Parida).

[1] Digital servitization as *the transformation in processes, capabilities, and offerings within industrial firms and their ecosystems to progressively create, deliver, and capture increased service value arising from a broad range of enabling digital technologies* such as the Internet of Things (IoT), big data, artificial intelligence (AI), and cloud computing.

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AI-enabled product–service systems (Akter et al., 2021; Sjödin et al., 2023). However, reviews of the literature on artificial intelligence in servitization and product–service systems reveal that the field is still in its early stages (Naeem et al., 2024). There is a need for further understanding the interplay between AI technology, ecosystem partnerships and the development of concrete AI-enabled PSS offerings (Thomson et al., 2022). The importance of artificial intelligence, smart product–service systems, and autonomous solutions cannot be overstated. There is a pressing need for theoretical exploration, conceptual development, and case studies in this area. Given the fast pace at which AI is evolving and transforming industries, research on the pathway toward AI-enabled, product–service systems is lacking, making it challenging for product manufacturers to adapt.

Second, further research is needed to *understand the role of managerial practices in steering the transformation towards AI-enabled PSS*. Practice theory (Jarzabkowski, 2008; Kohtamäki et al., 2022a,b; Whittington, 2006) could help understand the role of managerial agency and activities in shaping firm level AI implementation and commercialization. Moreover, despite the fact that servitization has often been explored through case studies, the literature, particularly on digital servitization, has been lacking practice-theoretical perspectives. Only a few studies have used the practice-theoretical lens to understand the processes in servitization. For instance Palo et al. (2019) focused on the contestation between a company's parallel business models. Kohtamäki et al. (2018, 2020a,b) focused on coping practices to manage the paradoxes of servitization. Löfberg et al. (2025) considered the role of practices in servitization. Korkeamäki et al. (2020) studied the role of discursive practices in managing legitimacy struggles in advanced services. Yet, none of these previous studies focused on the role of practices in AI-enabled product–service systems. We contend that, given the disruptive nature of AI, distinct managerial practices may be required to unlock its potential within PSS. For example, what practices are critical in instigating AI transformation, and how do these practices need to change as companies mature and seek broader commercialization of AI-enabled PSS. Therefore, there is a need for new studies to examine the processes and practices involved in achieving innovation in AI-enabled product–service systems.

Considering this background, this study aims to investigate the question: *How are managerial practices evolving to facilitate the transformation process toward AI-enabled product–service systems?* This study contributes to the literature on digital servitization and product–service systems, focusing on the role of artificial intelligence in servitized product manufacturing companies. The research utilizes a unique single case study of a leading manufacturer who creates moving autonomous product–service systems for global logistic operators. The study makes two main contributions. First, the study illustrates the novel interplay between AI-enabled PSS, AI-related PSS technologies, and AI-related PSS ecosystem partnerships, in the company's transformation toward AI-enabled product–service systems. Second, the study identifies the managerial practices needed during different phases of this transformation. The case study highlights the AI journey of a manufacturing company who is a global leader in autonomous solutions, providing a benchmark for managers planning their digital servitization journeys. Furthermore, the study proposes a research agenda for future studies.

## 2. Theoretical framework

### 2.1. Digital servitization and product-service systems

From its infancy (Vandermerwe and Rada, 1988), over the past 20 years (Baines et al., 2007; Gebauer et al., 2005; Oliva and Kallenberg, 2003), servitization research has proliferated (Baines et al., 2017; Kowalkowski et al., 2017; Rabetino et al., 2018). Digital servitization is considered as one of the major research streams within the servitization research (Kohtamäki et al., 2019; Rabetino et al., 2021). Servitization literature includes business model innovation across organizations and ecosystems (See also Filosa et al., 2025), with specific emphasis on a variety of issues, such as digital servitization (Kohtamäki et al., 2019; Vendrell-Herrero et al., 2017), sustainable servitization (Kohtamäki et al., 2024a,b; Rabetino et al., 2024a,b), and AI-enabled product–service systems (Naeem et al., 2024; Sjödin et al., 2023). Various factors drive innovation in digital servitization, including IoT (Frank et al., 2019; Hasselblatt et al., 2018; Rymaszewska et al., 2017), the digital servitization process (Baines et al., 2020; Bustinza et al., 2017; Sjödin et al., 2020; Tronvoll et al., 2020), digital servitization business models (Kohtamäki, Leminen et al., 2024a,b; Luz Martín-Peña et al., 2018; Sjödin et al., 2023), digital platforms (Filosa et al., 2025; Hendricks et al., 2025), as well as organization and ecosystems (Canboy and Khlif, 2025; Hullova et al., 2019; Sklyar et al., 2019). Environmental trends, such as sustainability and the circular economy, are also significant drivers in this field (Rabetino et al., 2024a,b). Implementing autonomous solutions requires effective coordination between these elements to create structures (Thomson et al., 2022). Manufacturing companies often struggle with these types of activity (Burström et al., 2021), which are distinct from hardware manufacturing due to strong path dependencies (Brekke et al., 2024). These struggles may arise because manufacturing companies operate in relatively stable industries compared to more dynamic ones (Sydow et al., 2012; Brekke et al., 2024). Complementary resources and orchestrator capabilities are necessary for success (Jovanovic et al., 2021; Kamalaldin et al., 2021). Huikkola et al. (2020, 2022) investigated the firm boundary decisions of servitized product manufacturing companies, emphasizing the importance of understanding the customer. Moreover, industrial customers play a significant role in driving strategic decisions and investments, serving as a strong argument for re-identifying a product manufacturing company as a smart solution provider. Thomson et al. (2022) observed the interplay between technical systems development, ecosystem configuration, and business model design. Bustinza et al. (2024) found that servitization significantly mediates the link between AI-enabled manufacturing and value capture at ecosystems. Jia et al. (2024) identified three digital platform capabilities for digital servitization; data integration capability, data analytics capability, and data productization capability. Kohtamäki et al. (2019, 2021) theorized on the interplay between business models, strategic capabilities, and ecosystems. In technological transitions, manufacturers must learn to shape the markets proactively (Sandvik et al., 2024). Manufacturing culture is often too passive and risk averse (Brekke et al., 2024). The development of AI-enabled product–service systems require strong initiative and agency from manufacturers who may be too accustomed to traditional product manufacturing (Huikkola et al., 2022).

### 2.2. AI-enabled PSS

The present study explores AI-enabled PSS by using a multi-level research setting. We map AI-enabled PSS based on their technological development and contextualize them within their ecosystem partnerships (Sjödin et al., 2020). By ecosystem partnerships, we refer to organizational relationships between the case company and other companies, as well as public organizations that enable the creation and delivery of AI-enabled PSS (Jacobides et al., 2018; Möller and Halinen, 2017). We assume that no firm operates in isolation, and that the innovations in product–service systems occur within a business ecosystem driven by technological innovation and organized around integrated business-relationships, which we coin as partnerships. This also means that we focus these considerations on close business relationships instead of the broader institutional system (Tsvetkova et al., 2021). Therefore, we map the necessary technological innovations and ecosystems partnerships needed for creation of novel PSS, in which the evolution depends on the constant readjustment of processes, activities, and resources (Hsuan et al., 2021). In doing this, we distinguish the value chain processes, activities, and resources from the managerial practices needed to implement AI-enabled PSS (Kohtamäki et al., 2021).

In product–service systems and digital servitization, studies explore the role of artificial intelligence in PSS, embedded software, and AI-enabled digital services (Rabetino et al., 2024a,b). To define AI, we collected a few interesting definitions from prior literature (Table 1).

In the context of PSS we examine predictive maintenance systems (Rosati et al., 2022), defect identification (Selak et al., 2014), remote technologies, remote monitoring, control, optimization, and autonomous operation (Grubic and Peppard, 2016). The software component is central to these innovations, leading some researchers to prefer the term product–service–software systems, instead of product–service systems, in order to emphasize the role of the digital AI-elements and software (Coreynen et al., 2017). In this study, we use the term "AI-enabled PSS" to emphasize AI's role as an enabler of innovation in product–service systems (PSS). Thus, although AI may not have agency in the way human agents have, the advancement toward artificial general intelligence (AGI) may change this in the near future. Building on the definitions on Table 1, we consider AI as a technology that enhances the PSS through human-like intelligence, including activities such as perception, reason, interaction and problem solving (McKinsey & Company, 2024). Thus, AI holds much potential for developing more intelligent and autonomous product-service systems.

The transition from manufacturing to AI-enabled PSS requires technological capabilities (Perifanis and Kitsios, 2023). One of AI's primary uses is to support decision making at various levels by retrieving past information and enabling learning from it (Ayala et al., 2025). An essential tool for this purpose is case-based reasoning, which involves retrieval, reuse, revision, and retention by analyzing knowledge repositories (Corchado and Laza, 2003). Moreover, artificial neural networks help with information and knowledge management, enabling anomaly detection and isolation (Relich and Pawlewski, 2018). Researchers propose an autonomous smart service migration framework, to make optimal service migration decisions and to balance assembly line problems in product development (Huang and Abnoosian, 2020; Kucukkoc and Zhang, 2015).

Since 2010, studies on the employment of AI analytics have been increasing. Researchers began to provide enhanced intelligence solutions to industrial problems, such as signal processing techniques (Selak et al., 2014), and multi-criteria, decision-making approaches (Chen et al., 2022). According to Tsang and Lee (2022: 11): *"Applied AI is of the essence to* support *the future development of digital servitization".* Chowdhury et al. (2025) suggested that AI-capabilities can enable alertness in the supply chain and therefore facilitate resource orchestration and re-institutionalization processes. AI can examine the product and service lifecycle before larger scaling is undertaken to avoid product failures (He et al., 2016). AI can also improve service delivery and form the foundation of smart services, such as augmented reality (AR) applications. Virtual reality applications can support training through simulations to implement service tasks in the field (Gäthke, 2020). Advanced AI technology, particularly deep learning methods, bring the evolution of full autonomy one step closer to reality. Deep learning has supported navigation, guidance, and control (NGC) systems in maritime software development (Qiao et al., 2023). Fleets of unmanned aerial vehicles (UAVs), or drones, are also autonomously navigated and controlled by onboard sensors and computing devices (Lai et al., 2023).

**Table 1**
Defining artificial intelligence for the context of product-service systems.

| Authors | |
|---|---|
| IBM (2024: 1) | *"technology that enables computers and machines to simulate human learning, comprehension, problem solving, decision making, creativity and autonomy"* |
| McKinsey and Company (2024: 1) | *"AI is typically defined as the ability of a machine to perform cognitive functions we associate with human minds, such as perceiving, reasoning, learning, interacting with the environment, problem solving, and even exercising creativity. Examples of technologies that enable AI to solve business problems are robotics and autonomous vehicles, computer vision, language, virtual agents, and machine learning."* |
| Verganti et al. (2020: 213) | *"AI is inherently a decision-making technology: it offers opportunities to automate many tasks relating to learning and devising solutions. When AI is applied to the context of innovation, it may therefore transform how decisions in innovation are made, especially in relation to how novel solutions (whether a good, a service, or a process) are created and tested."* |
| World Economic Forum (2017: 6) | *"Artificial intelligence (AI) or self -learning systems is the collective term for machines that replicate the cognitive abilities of human beings. Within the broader technological landscape, predictive maintenance in the cognitive era has the potential to transform global production systems."* |

From 2022, a relatively new term, AIoT, began to be used for the integration of AI with the Internet of things (IoT). This refers to using the internet to transmit information and commands between devices, while AI handles the decision making (Kuo et al., 2022). This technology is effectively used in agriculture or AIoT drones (Chiu et al., 2022; Lai et al., 2023). However, before this terminology was adopted, a deep learning Internet of vehicles concept was used to avoid crashes and predict risks between vehicles (Chang et al., 2019). Addressing such life-dependent risks is essential for autonomous solutions before companies completely re-design their business models (Thomson et al., 2022), and these studies provide some guidance on how the literature on AI in PSS has been developing. Table 2 covers examples of relevant studies regarding AI in PSS and digital servitization.

### *2.3. Managerial practices for the emergence of AI-enabled product–service systems*

The transition to AI-enabled product–service systems is complex and often requires significant organizational changes. Therefore, the managerial practices involved in this transition are an overlooked yet important issue that requires further inquiry. To determine how it is managed – specifically, the managerial practices used in the transition toward AI-enabled product–service systems – we use the practice-theoretical perspective (Seidl and Whittington, 2014; Whittington, 2006). Through the practice-theoretical lens, we examine managerial practice from a micro-level perspective. We acknowledge that these processes must extend beyond the boundaries of a single firm and include the larger business ecosystem. Therefore, innovations in PSS require a sustained effort from manufacturers and their managers as they navigate the ecosystem, create new markets, and form partnerships. These innovative actions that may lead to novel PSS begin from the micro-level, but grow towards the macro, as the agents carry the novelties across functions, firms, and partnerships, in the interplay between the micro and the macro. Managerial practices are critical when managing these interactions where managers shape their PSS through doings (Whittington, 2018) and sayings (Balogun et al., 2014).

Practices can take different forms, such as doings (routinized ways of working), sayings (discursive), sensemaking (common strategic thinking), material or sociomaterial (strategy tools), or institutional (e.g., historically ingrained patterns) (Kohtamäki, Whittington et al., 2022a,b). Practices are inherently social, routinized ways of working that carry over time and space, guiding and structuring the actual praxis (Jarzabkowski, 2003). Thus, practice theory places the *"ontological primacy on practices rather than actors"* (Chia and MacKay, 2007: 229). They often integrate social and material aspects – for example, the sociomaterial characteristics of AI-enabled PSS are created from the interaction between tangible innovations and their creators and users. Practice theory acknowledges the importance of agency, showing that novel PSS result from the interaction between a material or immaterial element and their users. Middle managers, along with top management, help develop and routinize practices and processes necessary for effective value chain operation (Rouleau, 2005).

Managers use "practical" and discursive practices to reflect and shape the actual work, known as praxis. Hence, micro and macro are in

**Table 2**
Primary studies on AI in PSS and digital servitization.

| Authors | Research focus from the perspective of AI in PSS | Methodology | Main Contribution |
|---|---|---|---|
| Burström et al. (2021) | Explores how manufacturing firms utilize AI to enable business model innovation within industrial ecosystems. | Interviews with thematic analysis | Exploring how manufacturing firms utilize AI to enable business-model innovation with emphasis on the dynamics of value creation, delivery, and capture. |
| Cong et al. (2022) | Builds an iterative design strategy based on machine learning to optimize customer satisfaction forecasting. | Case Study | Th smart product–service system is an evolving technology in the services marketing model that utilizes smart, linked items and provides services to function as a resolution package to increase individual user happiness. This paper provided an iterative design strategy based on machine learning to optimize customer satisfaction forecasting in the smart PSS environment. |
| Farsi & Erkoyuncu (2021) | Agent-based modeling and uncertainty quantification using AI to understand product–service systems (PSS) | Case Study | This study analyses servitization and the related cost-benefit analysis approaches from the perspective of original suppliers' equipment. A probabilistic cost-benefit analysis approach involving PSS is incorporated into the framework. The simulation model offers extensive knowledge on the profitability and efficacy of service contracts from the supplier's position. |
| Haber & Fargnoli (2020) | Quality function applied to a service environment by combining the analytic hierarchy process and fuzzy logic. | Case Study | This study focused on the assessment of customer requirements in the context of service implementation in a product–service system (PSS). When it comes to understanding the intangibility of services and, therefore, assessing and prioritizing client requirements, traditional product design methods, such as quality function deployment, are restricted. To overcome this issue, quality function deployment is applied to a service environment by combining fuzzy logic and the analytic hierarchy process in order to reduce errors. |
| Heinis et al. (2018) | Upgrading the pricing model with machine learning to support PSS. | Case Study | Alternative pricing models, including pay-per-use are required for advanced services. This article presented a better set of consumption metrics, utilizing machine learning. These indicators capture value and enable effective assessment of the depreciation, and they allow the development of pay-per-usage methods for a greater variety of industrial support items and product–service systems. |
| Häckel et al. (2022) | Predictive capability development using AI in the payment structure. | Design Science Research | AI and servitization alter how industrial organizations generate revenue. Corporations deploy AI categorization systems to offer high-quality services at predictable prices. Predictive capacity is a crucial component in selecting a proper pricing structure and the design process of service agreements. |
| Kohtamäki et al. (2022a, b) | Extends the theory on digital servitization and smart solutions. | Systematic review with configurational approach | The study proposes an analytical framework that integrates business models, technologies, and ecosystems, facilitating the transition toward smart solutions with emphasis on managerial practices to navigate the complexities of digital servitization in autonomous ships. |
| Qvist-Sørensen (2020) | Automation using data-driven production and machine learning. | Conceptual Study | Servitization helps manufacturers to increase revenues, integrate further into the customers' supply chain, and boost their competitive advantage. The European car |

(continued on next page)

**Table 2** (*continued*)

| Authors | Research focus from the perspective of AI in PSS | Methodology | Main Contribution |
|---|---|---|---|
| | | | industry must re-evaluate its business models and create more agile organizational structures. |
| Sassanelli et al. (2022) | Result-oriented, product–service system (PSS) is introduced in the cyber-physical systems using AI and IoT. | Survey-based Research | The purpose of this research was to introduce a technology that enabled the PSS operator to combine power consumption from many structures and use new technologies to evaluate consumption and deploy technology. |
| Sjödin et al. (2023) | Conceptualizes AI-enabled circular business models (CBMs) for industrial firms | Multiple case study with six manufacturing companies | The study identifies two novel classes of AI-enabled CBMs: augmentation and automation business models, detailing their sustainability impacts. The study emphasizes the role of value discovery, value realization, and value optimization in the commercialization of circular business models. |
| Sjödin et al. (2021) | Explores how manufacturing firms can develop AI capabilities | 42 interviews | The study presents a framework that illustrates the AI capabilities, such as data pipeline and algorithm development, to exploit AI-related business opportunities effectively. The study explores how AI capabilities can be developed and integrated into business models to enhance digital servitization. |
| Tsvetkova et al. (2021) | To understand the business ecosystem dynamics for value creation in the context of autonomous ships. | Interview and content analysis | This paper extends the business ecosystems perspective by focusing on the impact of institutional structures on value creation, delivery, and capture with emphasis on the role of regulative, normative, and cultural-cognitive institutions. |
| Tseng et al. (2019) | Automation of servitization-based supply chain | Quantitative Study | The findings emphasize sustainable operations and consumption, together with collaborative advantage. In SPSS sustainable consumption and innovation activities should be emphasized. |

constant interaction (Giddens, 1979; Whittington, 2010). In an ecosystem, managerial influence unfolds within socially embedded structures and competitive pressures (Adler, 2001). Regarding strategic management, it is suggested that the relationship between micro-level practices and the broader ecosystem can be understood by focusing on *"management practices-in-use as the primary unit of analysis"* (Jarzabkowski, 2004: 551). It is argued that micro and macro levels are connected through managerial practices, with the macro level being shaped by micro-level practices (Kohtamäki et al., 2021; Vaara and Tienari, 2011). Practices are routinized for effectiveness and efficiency benefits.

Empirical research in servitization and product–service systems has examined managerial practices, including those related to service innovation management. For example, Huikkola et al. (2022a,b) approached the topic through managerial heuristics, revealing simple decision-making rules in smart solution development. They identified rules related to process, boundary, preference, schedule, and stopping in innovation projects. Kindström, Kowalkowski and Sandberg (2013) explored the microfoundations that enable service innovation by manufacturing firms, while the transition from product manufacturing to product–service systems necessitate an identity change – for example, a change in the fundamental beliefs about who we are as an organization. Artificial intelligence represents such an identity shift for a product manufacturer.

## 3. Methodology

### 3.1. Research strategy and case selection

The present study uses an exploratory, intrinsic, and inductive single-case study approach with processual data over time (Creswell and Plano Clark, 2007; Easton, 2010). This enables us to detect and rely on multiple data sources concerning complex firm processes sufficient to develop new insights into a novel theoretical phenomenon of AI-enabled product–service systems from an integrated solution provider. We used a single case design to gather in-depth case data from a specific, contextualized digital servitization process, which established a foundation for further theory construction (Langley, 1999). We selected a provider of autonomous moving solutions as the case company to study in depth (Patton, 2014). The solution provider offers large integrated solutions for logistic operators. It is a technology leader in its field – for example, in digital services and offerings – and is one of the leaders in various global customer markets. Consequently, we view the case study as an excellent opportunity to delve into the role of AI-enabled PSS as part of the product–service systems of a provider of integrated autonomous solutions.

### 3.2. Collection and description of data

Data for the present single-case study (Yin, 2012) were collected through semi-structured interviews (Stake, 1995) with company managers, former employees, and other actors from the broader ecosystem.

The research team has collaborated with the case company for over eight years. This extended research collaboration has facilitated excellent access to in-depth processual data, such as meeting observations, notes, interviews, strategic reports, presentations, and workshops. Various sources increased the accuracy of the study and enabled the development of novel perspectives and insights into AI-enabling capabilities.

Informants were selected based on their involvement in business case formulation and technological solutions, providing a strategic perspective of the manufacturer's transition toward AI-based autonomous systems. Additional participants were identified using the snowballing technique, with the principal encouraged to recommend others who could contribute additional insights for the study. A broader understanding of AI-enabled services was gained through interviewing external ecosystem actors and verifying critical historical events and decision-making processes. The informants included former CEOs, managing directors of various business units, business development managers, after-sales managers, and participants from customer and partner companies occupying diverse roles, such as managing directors and project managers.

Interviewees responded to open-ended questions based on an interview guide. This framework was informed by overarching themes, such as crucial historical events and decisions, transformation processes, technology solutions, organizational characteristics, and business model architecture (Kohtamäki et al., 2021). As new insights surfaced from the collected data, the interview guide underwent continuous revisions and cross-verification with other informational sources, such as reports, webinars, and relevant literature. The research team conducted 72 in-person and digital interviews from 2017 to 2022 (Table 3), with some participants interviewed on several occasions. Digital interviews, conducted over Microsoft Teams and Zoom, became necessary when in-person interviews were impractical due to the social distancing required during the COVID-19 pandemic. Typically, all recorded and transcribed interviews lasted 45–90 min. Alongside the interviews, direct observations from workshops and internal meetings were collected. This was done to identify critical events, decision-making processes, and cross-verifying information.

### 3.3. Data analysis

The data analysis applied a thematic approach (Braun and Clarke, 2006). The analysis consists of six recursive phases: familiarization, initial coding, searching for themes, reviewing, looking for aggregate themes, refining, and reporting. Thematic analysis provides a framework for identifying patterns across large data sets while preserving empirical grounding in the data (Braun and Clarke, 2006). The data analysis was aided by NVIVO 12 software, which helped us to keep track of the growing set of initial codes, memos, and interesting quotations and segments from the data items and across the initial data set. To enhance transparency, we developed a data structure showing graphically how our analysis progressed from initial codes to themes and aggregate dimensions, and how it aided our search for patterns across the data corpus (Gioia et al., 2013). The first step of the thematic analysis was to familiarize ourselves with the data by listening and transcribing recordings from the interviews and making notes from the observed data. Relevant timeline segments and emerging ideas were captured as we went through the transcripts. Then, we began to create initial codes using open coding techniques to identify critical events, decision making, and the evolution of AI-enabling capabilities. The initial codes were primarily descriptive, aiming to capture the essence of the raw data that could inform the research question. The initial coding process could be characterized as inclusive. We incorporated some of the surrounding data to avoid losing context. Moreover, we made every effort to code for as many future themes as possible to avoid overlooking potentially essential data. Next, we searched for patterns in the initial codes across the data set. Identified links and patterns in the initial codes were collated into second-order themes to facilitate abstraction whilst preserving empirical grounding. The themes were reviewed in relation to the first-order codes and the second-order themes from the data set. To achieve the correct level of abstraction to address our research question, second-order themes were collapsed into aggregate dimensions. In the final step of the analysis, we theorized the logic of relationships between the aggregate dimensions and themes and the temporal order in which they were employed. As our research progressed, the analysis was conducted in parallel with the data collection, which was highly iterative. Consequently, codes, themes, and aggregates were revised, moved, removed, renamed, and redefined several times during the process. Our criteria for the prevalence of themes and codes were first based on their relevance (Braun and Clarke, 2006) in capturing issues that address the ongoing transition journey of the manufacturer toward AI-enabled PSS. (Fig. 1 and Appendix 1). Fig. 2 and Appendix 2 illustrate the managerial practices in the three phases of preparing, conceptualizing, and industrializing.

**Table 3**
Case and data description.

| Data collection method | Data characteristics | | |
|---|---|---|---|
| | Information | Type of data | Amount of data |
| *Semi-structured interviews* | Case company | 60 interviews | ~65 h |
| | External | 12 interviews | 12 h |
| *Document analysis* | Reports | Company reports from 1999 to 2020 | 21 reports |
| | Websites | Company website information | |
| | Press and media | Press releases | 3 |
| | Internal presentations | PowerPoint presentations | 10 |
| *Direct observation* | Meetings | Project meetings | 10 |
| | Workshops | Company workshop | 2 |
| | Informal interactions | Short interactions (phone calls, emails, short discussions) | 20 |
| *Webinars* | Company | Public company webinars | 6 webinars with 20 presentations |

## 4. Findings

### 4.1. The case context

Our case company is a leading Norwegian multinational manufacturer with a strong presence in the B2B market. With a workforce of 12,000 employees, 40 % of whom work internationally, the company's maritime division is the focus of this study. This sector employs 7000 people across 60 local offices in 32 countries, providing equipment and solutions for over 30,000 vessels. Its customer base includes advanced offshore and research vessels, cargo and passenger ships, large fishing boats, naval vessels, and offshore units in the aquaculture, oil and gas, and wind power industries. As technology rapidly changes, its product portfolio includes offerings that support low and zero-emission operations, as well as remote-controlled and autonomous functionalities. The company plays a crucial role in promoting environmentally friendly marine operations and supporting sustainable ocean activities, extending its impact beyond industry. Its commitment to ecological responsibility has attracted attention and positioned it as a global influencer in advocating sustainable business practices in the maritime sector. This maritime technology innovator has been at the forefront of development since the 1960s, continuously adapting to technological advancements and industry shifts. The choice of this company as the subject of our study stems from its long-standing global leadership position, emphasizing its influence in shaping the maritime technology landscape. In response to changing global concerns, the company has strategically positioned itself as a catalyst for change. Since 2016, it has

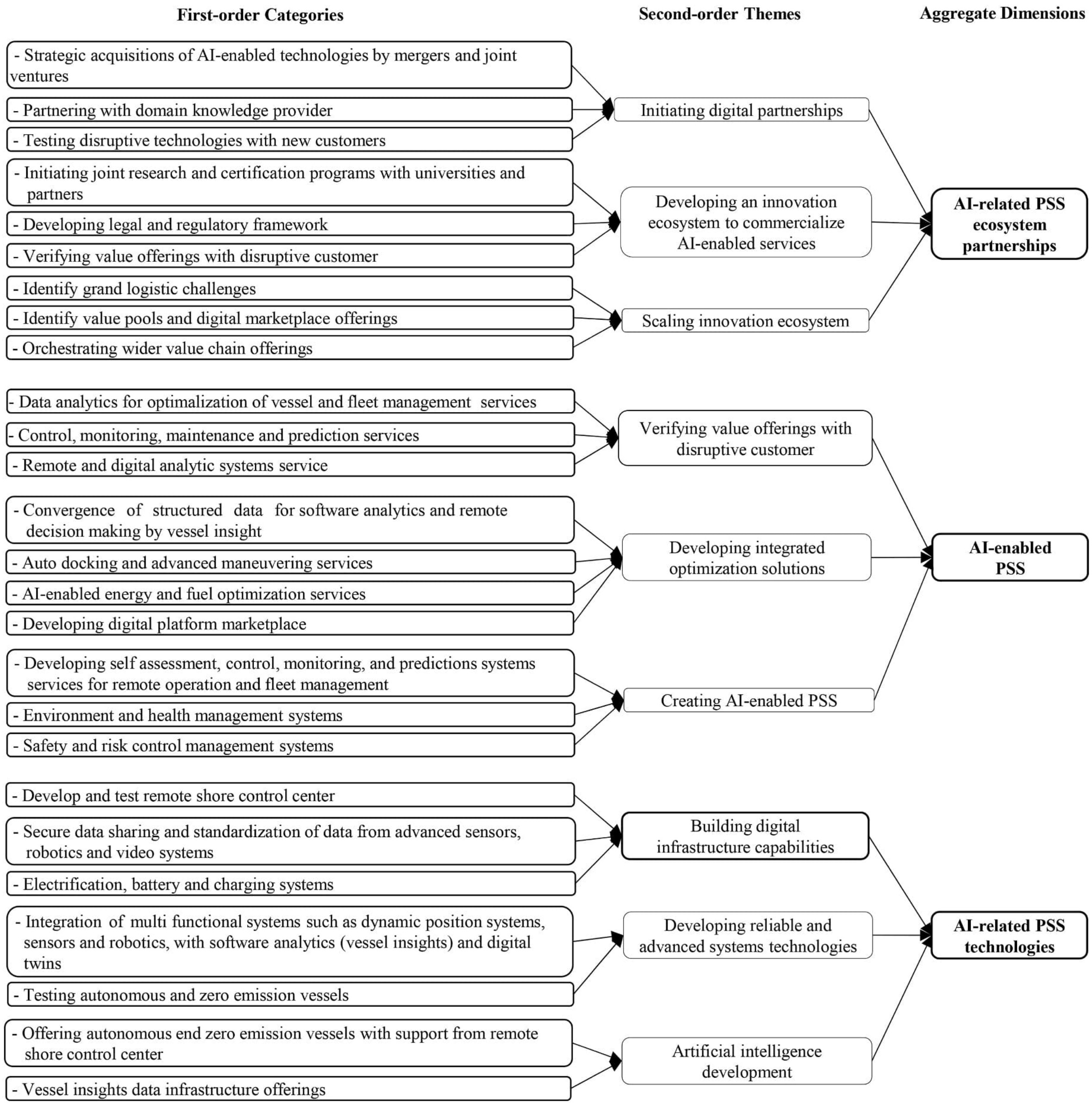


**Fig. 1.** Data structure on the evolution of capabilities.

focused on cutting-edge technologies to build a carbon-neutral ocean economy. As part of this commitment, the company is actively working to provide the most advanced digital product–service systems. This includes the development and implementation of autonomous sea drone technologies, demonstrating a dedication to innovation alongside sustainability. By concentrating on these initiatives, the company not only aims to meet current market demands but also strives to establish new industry standards, reflecting a forward-thinking approach that aligns with emerging environmental and technological trends.

### *4.2. Journey toward AI-enabled PSS*

In this case study, we will first explore AI-related PSS technologies and AI-enabled PSS, followed by AI-related PSS partnerships in the ecosystems. These core topics will be presented through a timeline with various dimensions (Fig. 3). Next, we will discuss the managerial practices employed to manage the transition to AI-enabled product–service systems. This shift can create significant challenges for companies in different industries and may be particularly daunting for product manufacturing companies with a strong product-focused manufacturing identity and culture (Brekke et al., 2024; Huikkola et al., 2022). As we assessed the company's efforts to build AI capabilities for autonomous solutions, the informants emphasized the importance of having a thorough understanding of the complex systems that have evolved throughout this process. The complex nature of creating new value propositions for autonomous solutions demands a comprehensive understanding of the technological landscape, which includes both the current state and the potential trajectories of AI advancements.

Moreover, the informants were acutely aware of the critical role that legal factors play in shaping the implementation and deployment of AI technologies. As the company explores autonomous solutions, managing legal frameworks becomes an essential task. The informants stressed the need for a proactive approach to address potential legal challenges, ensuring compliance and mitigating risks linked to advanced technologies. Additionally, the informants highlighted the necessity of launching disruptive solutions into the market. They pointed out that understanding the technology and legal aspects is insufficient in itself; the ability to innovate and introduce groundbreaking solutions is equally important. This requires not only keeping pace with technological developments but also strategically positioning the company to steer

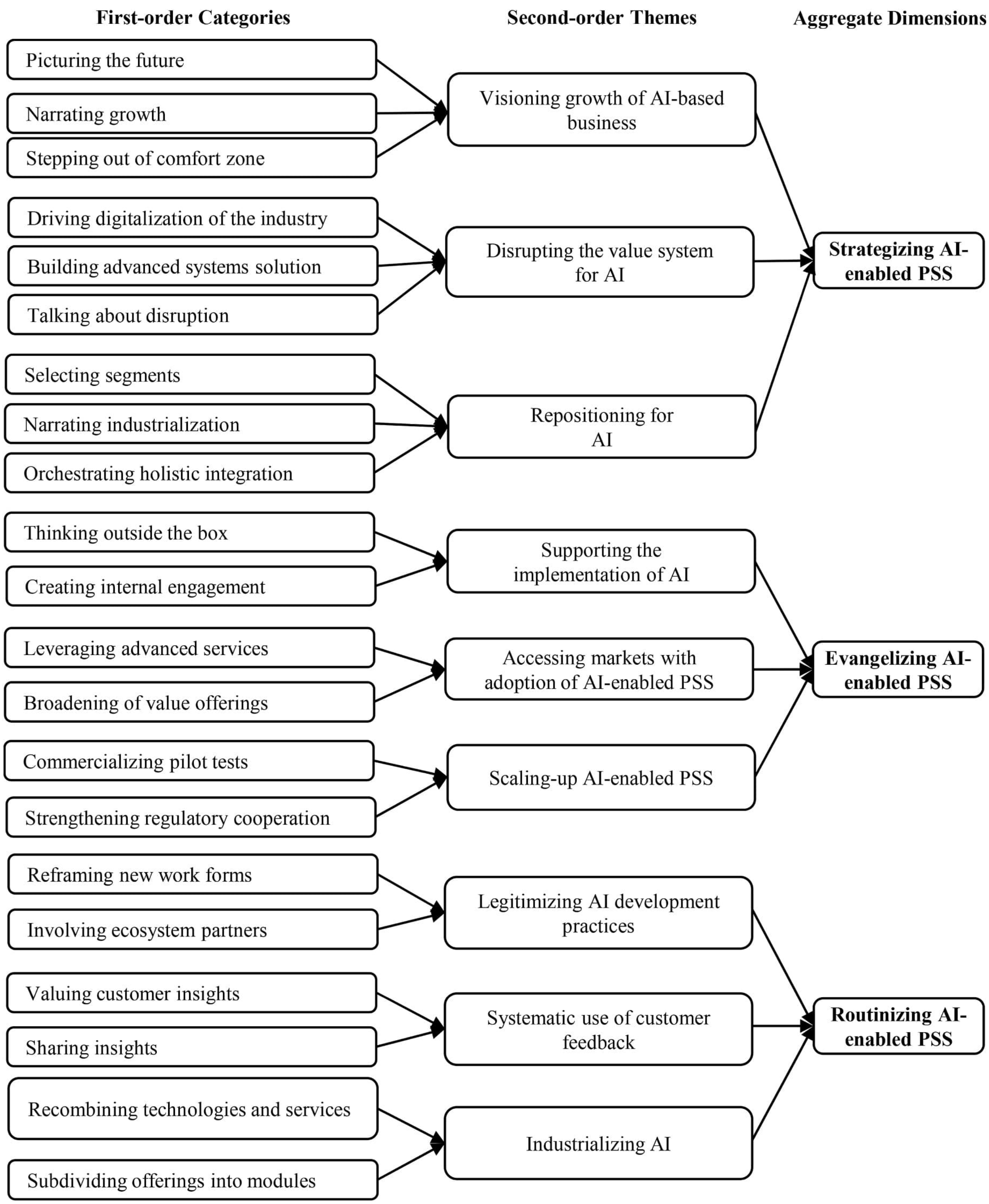


**Fig. 2.** Data structure of managerial practices.

industry changes. Above all, the informants stressed that successfully integrating AI capabilities into autonomous solutions requires a multifaceted approach that combines technological knowledge, legal expertise, and a proactive attitude toward disruptive innovation.

In evaluating the case company's efforts to develop AI-enabled PSS, we created a timeline showcasing significant AI-enabled PSS developments for autonomous solutions (Fig. 3). The year 2015 marks the starting point, when systems achieved digital connectivity resulting in lower costs. Digital connectivity was enabled by more advanced microprocessors and improved bandwidth. This digital connectivity evolution enabled large volumes of data transfers for processing in real time at reasonable cost. In the next section, we provide a more detailed discussion of these three critical components, emphasizing their interconnections and the strategic considerations needed to navigate the evolving landscape of AI-driven autonomous solutions.

*4.2.1. AI-related PSS technologies*

As product manufacturing firms move toward AI-enabled PSS, the demand for improved competencies and the integration of existing automation technologies into advanced multifunctional systems grows. Our case study identified three key components reflecting the need for capability development. The first key component is developing a strong digital infrastructure, which is part of preparing the company for advanced digital PSS (2015–2018). This is vital to ensure safe and

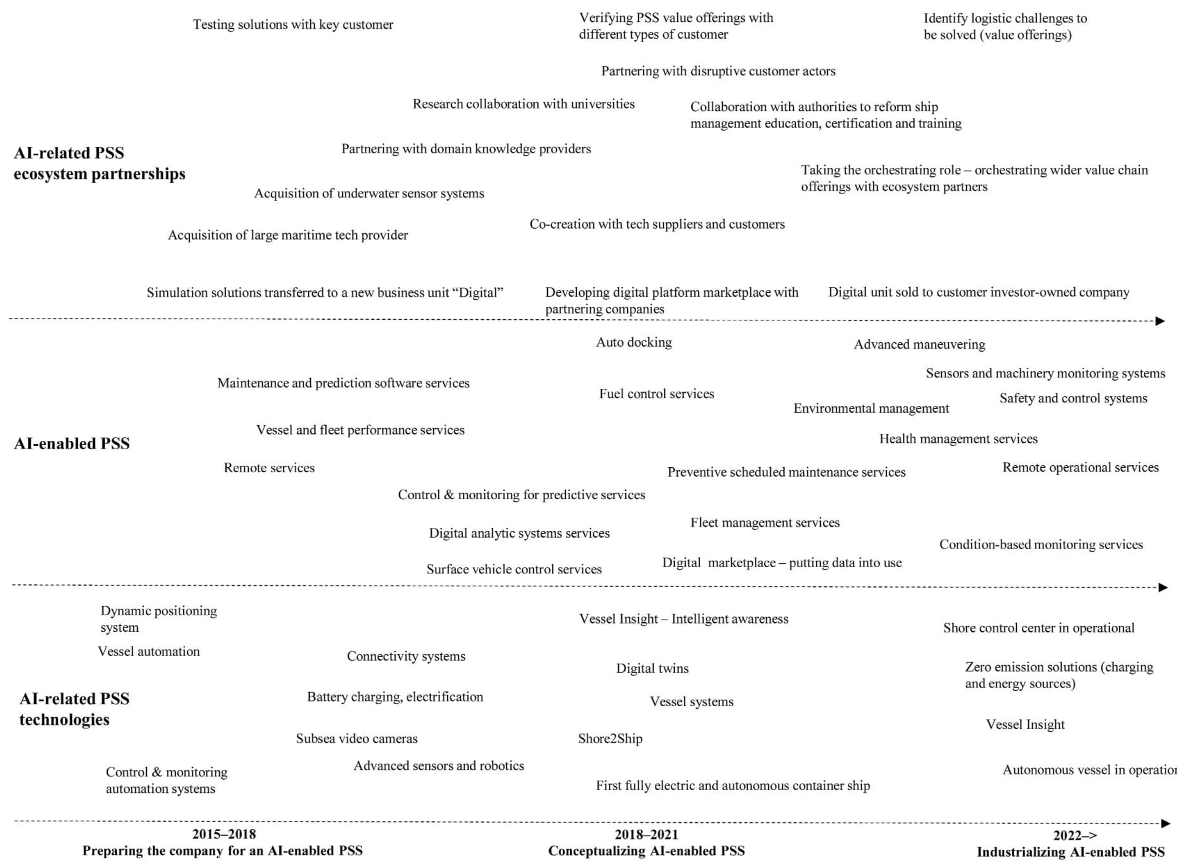


**Fig. 3.** Evolution of AI-related PSS ecosystems partnerships, AI-enabled PSS, and AI-related PSS technologies.

reliable information exchange between autonomous vessels and control and monitoring services, whether through shore control centers or ship-to-ship communication. In addition to developing digital infrastructure, the second component included integrating well-established systems technologies, which is part of the conceptualization (2018–2021), such as dynamic positioning and control and monitoring systems, with software analytics utilizing cameras and sensors, along with the development of digital twins. According to one informant: "*The components needed in an autonomous vessel has been tested for years, it is 40 years ago. It has been tested in many other areas such as camera systems used in the airline industry, and the defense industry. What is new is putting those technologies together and creating a fusion of sensors, cameras, and an autonomy brain on the vessel that can replace the human situational awareness.*"

Establishing processes and activities for accessing, securing, and standardizing high-quality data for digital twins and analytics is integral to this initiative, ensuring the system's overall efficiency and reliability, which is essential for tasks such as securing the efficient charging of electric vessels or exploring new energy sources for climate-neutral performance. Keeping in view global efforts, such as the Paris Agreement and national strategies for reducing carbon emissions, there is an increased emphasis in the shipping industry on prioritizing technologies such as electrification, hydrogen, ammonia, batteries, and supporting infrastructures as alternatives to traditional fossil fuel-based energy sources.

Furthermore, the third component stresses the complete industrialization (2022 onwards) of AI, which will decrease the need for human intervention aboard vessels. The integration of AI-based autonomous solutions is critical in this transformation, given their potential to enhance resource efficiency compared to conventional crewed and fossil fuel–powered vessels.

From 2002, automatic identification systems became mandatory on all ships, showing the position of vessels, which allowed operators to track competitors' ships. A case in point is the development of the dynamic positioning (DP) system in the 1970s, launched in 1977 to maintain a vessel's position, saving fuel and reducing wear on propulsion equipment. Eventually, dynamic positioning technology evolved into a stand-alone dynamic positioning system interfaceable with other systems, including electronic chart and display information.

By 2015, the previous dynamic positioning systems had transformed into an integral part of a new, integrated dynamic position system that communicated with other advanced operational systems, such as shoreside logistics, offshore support, and remote operational vessels, using dual Ethernet Lan. The development marked a major advance in connectivity, enabling data and information sharing with other advanced digital systems (control and monitoring of autonomous systems) for real-time intelligent decision making – both human and non-human – a foundation for full vessel autonomy (as illustrated in Fig. 3). In subsequent years, the company invested significantly in state-of-the-art digital sensors, robotic technologies, sub-sea video cameras, Internet of things connected systems, software analytics, digital twins, and battery-powered vessels. These new technologies were evaluated in pilot programs to assess their reliability and the operational risks for autonomous vessels. Following several years of trials, a fully autonomous vessel was constructed and launched for commercial use in 2022.

This forward-thinking approach places the company at the forefront of technological innovation in the maritime sector. Building capabilities for AI-enabled PSS is challenging, as seen in our case study. "*Offshore activity, trade fleet activity, and total logistics become more digitalized. With digitalization, you can put logistics in a broader view, such as combining road transport, reloading, and vessel transport. This is more dependent on digital solutions and remote operation centers, where people with overview and competence can use data for fleet management and advanced logistic operation.*" For example, Sjödin et al. (2020) suggest micro-services as one solution to this issue.

#### 4.2.2. AI-enabled PSS

Simple machine learning maintenance and prediction systems start as the humble beginnings of the AI-based PSS in the case company. The digitalization of shipping gained momentum between the late 1990s and early 2000s, as global satellite systems (AIS) provided nearly global coverage, and electronic engines combined with sensor technology allowed equipment manufacturers to monitor the condition of engine and ship performance. From 2002, automatic identification systems became mandatory on all ships, showing the positions of vessels, allowing operators to track competitors' ships. So, the preparation phase of digitalization had started. However, the integration with PSS did not start until 2015–2018. According to one informant: *"From our side, the software is when the brainwork comes in. So that is the smartness, and the hardware is just the enabler to perform that functionality. So, we are shifting a bit away from hardware focus towards what kind of benefits, services, kinds of functionalities, what kind of added value you are getting from the software."*

Moving toward the conceptualizing phase (2018–2021), in addition to enhancing connectivity and developing PSS, the company allocated resources to a joint venture to establish a remote operational center (ROC). This center was designed to oversee a single vessel or a fleet of autonomous vessels from a distance with minimal human intervention. The autonomous vessel, being commercially active, transports products from three different locations with minimal human involvement. One informant regarded this as a cost saving: *"As I see it, the value or remote operation center (ROC) is the many levels of services and products that can be in the same offering such as fleet monitoring. This is important as it can optimize and monitor the fleet and make cost savings possible as one person can control multiple vessels and reduce manning on the vessel."* Moreover, the organization funded the development of sophisticated digital software and infrastructure to advance analytical capabilities related to maintenance, predictions, fleet performance, fuel consumption, and environmental management systems.

An informant described developing AI-enabled PSS to directly target the cost of their shipping customers. For example, for customers operating a vessel, whether in short-sea or deep-sea contexts, significant costs are involved due to heavy investment in ship design and construction, maintenance, crew accommodation, port operations, and fuel consumption (Tsvetkova and Hellström, 2022). Accordingly, the case company developed autonomous ships with technologies that can reduce design, building, and operational costs by minimizing the number of crew members needed on board, thus eliminating the need for additional accommodation. These changes lead to increased crew safety and allow ships to travel at lower speeds to cut fuel costs or transition from fossil fuels to cleaner energy sources, such as batteries, gas/fuel cells, or other zero-emission options (Munim, 2019). This solution not only improves operational efficiency but also transforms the traditional maritime landscape. The new AI-enabled PSS aims to revolutionize vessel management, providing remote monitoring and control capabilities from an onshore operational control center. This can be achieved by integrating existing systems, such as control and monitoring, alongside digital position systems, and connectivity. The company can ensure compatibility with maritime and land-based logistics infrastructures.

A notable aspect of this initiative is the implementation of AI-related technologies, including cameras and sensors, which elevate the service software to a higher level. It is argued that this software is designed to offer a range of intelligent functions, from smart predictions and fleet performance analysis to creating digital twins and fuel-saving services. The aim is to improve operational efficiency and provide data-driven insights that enhance decision-making speed and quality. As full-scale industrialization takes place, concerns related to safety and control systems also arise. According to one informant: *"Then you have these heavy shell transport with a lot of tank boats with a lot of floating goods that they move around the world on large boats, large values, and they can have a huge effect on the environment if accidents happen. So, they have another motivation that lies in navigational security."* Hence, the safety and control systems and monitoring services based on AI-enabled PSS need to be fully operational.

#### 4.2.3. AI-related PSS ecosystem partnerships

Ecosystem partnerships have a critical role in facilitating the creation of AI-enabled PSS. Ecosystem partnerships refer to organizational relationships between the case company and other companies and public organizations that enable creation and delivery of AI-enabled PSS (Kohtamäki et al., 2019). One of the critical technological capabilities necessary for transitioning AI-based PSS to autonomous solutions is the ability to innovate within an ecosystem, orchestrating collaboration with diverse but independent product developers or service providers (Jacobides et al., 2018), but also to develop relationships with public and non-profit organizations impacting on the governance of the ecosystem. Therefore, creating effective strategies is vital, particularly regarding the resources required to develop and leverage such an innovative ecosystem for new autonomous offerings (Perifanis and Kitsios, 2023). The case analysis identified three essential resources: initiating and orchestrating digital partnerships, using the ecosystem to win digital partnerships, and using the ecosystem to gain competitiveness by creating AI-enabled PSS and scaling up the AI-enabled PSS ecosystem. First of all, to prepare the company for advanced digital PSS (2015–2018), establishing a digital partnership to acquire AI-enabling technologies is crucial. This is particularly relevant when introducing disruptive product–service systems, such as autonomous vessels and logistics operation. The case company notes that, while this transformation is just beginning, the full impact of autonomous maritime logistics on national and international goods transport – and, more broadly, the overall movement of goods on land and sea – has yet to unfold. To stay ahead of this evolution and establish a competitive advantage, the company has been investing heavily in mergers with firms that possess critical AI technologies. At the same time, the company has been pursuing joint ventures and partnerships with organizations capable of providing cross-sector ecosystem services. Deploying new technologies in a heavily regulated market necessitates general and specialist knowledge contribution (Queiroz et al., 2025) such as maritime law, international standards, compliance, ship operations, and technology development.

Second, collaborations are needed to navigate all legal aspects of commercializing autonomous vessels and leading the standardization of necessary infrastructure. Understanding the complex regulatory environment maintained by organizations such as the International Maritime Organization (IMO) is especially important when introducing safe AI-based autonomous vessel solutions because unmanned and automated vessels challenge existing maritime and safety regulations. Autonomous vessels could have the capacity to provide a safer, more efficient, and future-proof maritime sector (Humphries et al., 2023). The case company formed alliances to gather knowledge involving intensive research collaboration with universities, regulatory bodies, and other strategic partners. This collaboration helped to create new certification types, testing, verifying technologies, and building a foundation to empower regulators to amend existing laws or introduce new ones, facilitating the entry of AI-based autonomous solutions into the markets.

The case study findings highlight close collaboration between the focal company and regulatory bodies, alongside other strategic industrial partners. According to one informant: *"There is a new wave of cooperation because the shipping industry understands that we can't do this alone. That is new because we used to do everything on our own. This digital disruption leads us to wake up and find partners outside shipping to get to this next level of digitalization."* This collaboration involved a comprehensive exercise to uncover the implications related to vessel staffing, identifying functional and operational requirements, and defining the roles and responsibilities of participants. By enabling the introduction of disruptive technologies, such as AI-based autonomous systems, the company was able to transform service delivery through unique technological features while creating radically changed marketplaces and service relationships (Guo et al., 2019).

Third, the maritime industry is often viewed as conservative because many ship owners tend to delay investments in digital technologies until they can demonstrate an ability to lower operational costs (Sandvik et al., 2024). Demonstrations of the technological capacity through concept studies have not been enough to generate excitement among these cautious ship owners. A breakthrough occurred in 2017 and 2018 when two non-maritime companies ordered autonomous and zero-emission container vessels. This marked a turning point for the company because the value offerings could be tested and verified on a full operational and commercial scale. A digital marketplace for software analytics (software as a service) was also established as part of this effort. To achieve these goals through full industrialization (2022 onwards), the company aimed to enhance ecosystem capabilities by acquiring firms with essential knowledge or by partnering with capable firms to innovate and disrupt the current value system. One informant explained: *"What we have tried to do is that our company is a technology provider, and the partner is coming with the operational and domain knowledge. So, they are giving us the requirements from the operator side, and then we are transforming that knowledge into products, solutions, and systems functionalities."* This disruption included designing new types of solution, developing new supportive technologies, operating and controlling vessels, and providing comprehensive logistic services, which led to the further orchestration of wider value chain offerings with partners.

### *4.3. Managerial practices for the evolution of AI-enabled PSS*

#### *4.3.1. Presentation of the managerial practices*

Managing the evolution of AI-enabled product–service systems involve overseeing the development, deployment, monitoring, maintenance, and optimization of various capabilities that contribute to the development and operation of artificial intelligence systems, such as autonomous vessels management systems. In the case study, we identified the evolution of managerial practices across the three periods: 1) Preparing the company for an AI-enabled PSS; 2) Conceptualizing AI-enabled PSS; 3) Industrializing AI-enabled PSS. In these three phases, we identified the influence of three managerial practices: 1) Strategizing AI; 2) Evangelizing AI; and 3) Routinizing AI. We find that the three managerial practices evolve over time through the phases, somewhat following the evolution of the AI-enabled PSS. Within the three managerial practices, we identified nine activities. This section of the analysis builds on the three managerial practices by analyzing them and then discussing their evolution over time.

It is important to understand that the evolution of managerial practices shown (Fig. 4) is dynamic in nature. That is to say, one resource component triggers progression in the other and, hence, AI-enabled PSS triggers progression in AI-related technologies. Consequently, the role of AI-enabled PSS leads to the evolution of AI-related PSS ecosystem partnerships. Thus, AI-related PSS technologies, AI-enabled PSS, and AI-related PSS ecosystem partnerships evolve through an interplay, facilitated by managerial practices.

First, *strategizing AI* refers to the managerial practice that drives strategic analysis, sense-making, and decision making in AI-enabled PSS. The aim of AI-strategizing practices is to guide the company and its employees away from traditional product manufacturing toward AI-enabled product–service systems. While ongoing strategizing is essential, it also becomes adopted over time. Initially, when preparing to be more digitally inclined, the company focused on the need for growth through digital PSS (embracing growth). This evolved into challenging the existing value system by creating new types of advanced service. Specifically, it involved narrating this disruption both internally and externally to transition from conventional methods to innovative approaches centered on AI-enabled digital PSS. Ultimately, the goal is to reposition and refine managerial practices to achieve the right market fit and integrate product, service, and AI capabilities for the effective

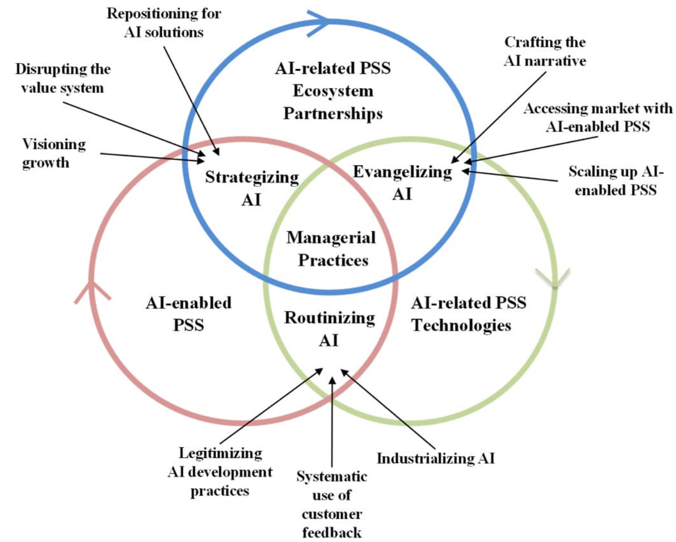


**Fig. 4.** Managerial practices and activities to facilitate AI-enabled PSS.

industrialization of autonomy. As an interviewee stated: *"People are used to selling service agreements and propellers. Selling digital solutions is a whole other industry."* Consequently, repositioning is essential. Embracing growth was not just about adopting new technologies but about transforming the entire business model to be more data driven and responsive to market changes. This led to forming new partnerships with external AI solution providers, which brought in additional expertise to facilitate innovation. These collaborations enabled the company to explore cutting-edge applications, from predictive maintenance to customer behavior analysis, further enhancing its product service digital offerings (i.e., new revenue streams).

Second, *evangelizing AI* involves more than just adopting new technologies; it requires managerial attention to create a discourse that embraces growth in advanced forms of digital innovation and greater adaptability within the organization. In order to forge new beginnings and shift toward AI-enabled PSS by creating new organizational structures, the company will need a commitment to not only embrace current AI capabilities but also shape a future where AI-enabled offerings, technologies, and collaborative partnerships are essential for the organization's identity and success. Thus, internal and external support is required to implement AI. Evangelizing involves helping with the rollout of AI-enabled PSS to initiate future market positioning. It should be noted that "accessing markets with AI-enabled PSS" is not done at once. One informant explained: *"It is a long period of testing out in real life scenarios with crew onboard and gradually allowing the automated systems to take over more and more of the operation, until the legislative bodies feel satisfied that it is a safe operation, and they will* grant *approval for the vessel."* When new streams of income are accessed through AI-enabled PSS in some markets, this is replicated in other markets, causing the "scaling up" of AI-enabled PSS. This includes urging stakeholders to invest a variety of tangible and intangible resources, such as human and financial capital, into more ambitious and potentially riskier AI-enabled PSS.

Third, *Routinizing AI* relates to managerial discourse that facilitates the legitimation of AI within organizations and the ecosystem. Routinizing drives more than the adoption of new AI-related technologies. It is about promoting a mindset where AI is viewed not as a new but as a vital, everyday feature of operations with ecosystem partners – thus, "crafting the narrative to legitimize AI". To achieve this, managers need to use narratives to legitimize AI and developmental activities, cementing the everyday use of AI in PSS and related operations. By creating a discourse that values and trusts AI-enabled services, the organization can facilitate broader adoption of these technologies.

Prioritizing resources is another important aspect of routinizing AI into operations. By allocating resources and doing so in a way that emphasizes the sustainability and continuous improvement of AI-enabled services, the organization endorses the notion that AI is not just a one-time project but an ongoing, evolving element of its product–service system portfolio. This work aims to make AI a routinized praxis (a practice). By addressing internal attitudes, user perspectives, and resource allocation, the organization not only ensures the success of current AI initiatives but also establishes a foundation for a future where AI becomes an essential and routine part of its business strategy.

Furthermore, focusing on customer insights is central to the routinization process. Understanding user needs and preferences is crucial in adapting AI solutions to effectively meet real-world demands by offering customized solutions based on modularization of product–service systems. One informant reported that: *"It is quite difficult for us to have domain knowledge on any single process or any single vessel type, or every single operation. It is a journey together with the customer."* By integrating and "systematically using customer feedback" in the ongoing development of AI-enabled PSS, the organization ensures that these technologies align closely with customer expectations, thereby enhancing their routine usage and acceptance.

Lastly, in the phase where "industrializing of AI" becomes part of routinizing, the scaling up and repositioning happens simultaneously. One of the informants reported: *"The phase we are in now is a scaling phase. We would like the infrastructure to be on a lot of vessels. When a lot of vessels are sending data to shore and the different needs of the different customers become clearer, we will have a lot of functionalities, a lot of applications in the marketplace. We will also see that the customers would like to have digital twins of their vessels or rigs. This will give them a lot of publicity, and publicity creates curiosity. This will be an evolution in the coming year."* Thus, the evolution of the system continues apace.

### 4.3.2. Evolution of managerial practices over the three periods

Based on the analysis, we synthesize a process framework detailing the transformation toward AI-enabled PSS (see Fig. 5). The framework illustrates the evolution and interplay of managerial practices and AI-enabled PSS. We use the same three phases as we used in Fig. 3: 1. Preparing the company for an AI-enabled PSS, 2. Conceptualizing AI-enabled PSS, 3. Industrializing AI-enabled PSS. In each phase, iterative cycles of managerial practices and activities facilitate the stepwise development of AI-enabled PSS. Managerial practices can include both routinized managerial activities (doings), as well as discursive practices (sayings) (Kohtamäki, Whittington et al., 2022a,b).

In the first phase of preparing the company for an AI-enabled PSS (2015–2018), strategizing AI involved an "visioning growth" path for the company, which considers the preparation stage as getting the technology ready and adapting to growth in AI-enabled PSS. Managers' capacity to communicate the vision by engaging employees in accepting technological change, is critical when transitioning toward AI-enabled PSS. The management's commitment to growth, should shine through in their narrative to prioritize growth through AI-enabled PSS, considering the gravity and weight of the company's previous history, routines, and technology that builds on manufacturing (Brekke et al., 2024). In the second phase of conceptualizing AI-enabled PSS (2019–2021), strategizing AI focused on disrupting the traditional hardware-focused value system to accommodate and develop the AI-based opportunities. In this shift, the company is conceptualizing the new AI-enabled PSS to fit the market need, while disrupting the conventional market expectations as well as preparing the supply chain. Indeed, strategically, this is about creating new markets (Nenonen et al., 2019) while disrupting the previous value system as it existed. However, in phase three starting in 2022, strategizing AI enables repositioning the new AI-enabled PSS. This phase is a lengthy process, moving back and forth across the second and first phases. The progress is far from linear in these renewal processes. Overall, as strategizing progresses through the different phases, what

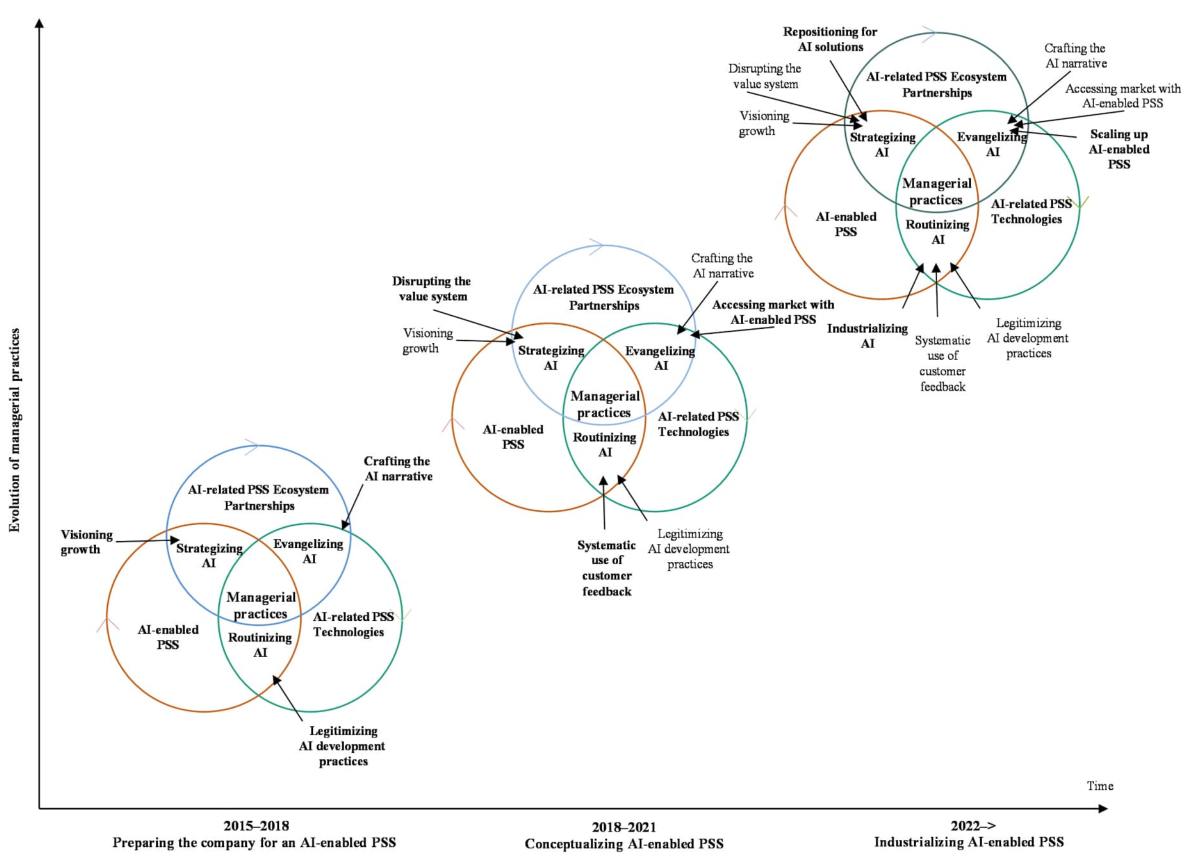


**Fig. 5.** Evolution of managerial practices from 2015 to 2022 onwards to manage the transformation toward AI-enabled PSS.

becomes obvious is the strategizing practice that enables creation of novel strategy that takes the company towards AI-enabled PSS.

Evangelizing AI, in the first phase (2015–2018), involved "crafting the AI narrative" in the future-oriented firm. The capabilities allow the company to offer new products and services based on AI, with intention to address emerging needs in the markets. In the second phase of conceptualizing the digital PSS (2019–2021), evangelizing AI focused on accessing markets with AI-enabled PSS opening up new revenue streams. In phase three, starting in 2022, the managerial practices focus on scaling up AI-enabled PSS, allowing the company to fully industrialize autonomous solutions. Thus, what works well in one market can be scaled to others.

Routinizing AI, at the first phase (2015–2018) involved "legitimizing AI development practices" to create credibility for AI-related PSS at level of the firm and the ecosystem. This managerial practice puts emphasis on the narrative that supports the legitimization of AI as indispensable and something that should be adopted on a larger scale in the ecosystem. "*Because digitalization as we have experienced comes down to domain knowledge. It is so important to know what kind of process is on board the vessel, or what kind of culture the company has, and you need to mix this together with the technology. It is quite difficult for us to have domain knowledge on any single process or any single vessel type, or every single operation. It is a journey together with the customer.*" This shows the commitment to AI-enabled PSS to ensure that the ecosystem remains at the forefront of technological advancement, capable of adapting to new challenges and opportunities. In the second phase, conceptualizing AI-enabled PSS (2019–2021), routinizing AI manifests in the managerial practice that encourages the "systematic use of customer feedback" for continuous improvement to support the creation of attraction towards AI-enabled PSS. In phase three, starting in 2022, the managerial practices focused on industrializing AI-enabled PSS. "*It is very important for us as a company to have solutions which are closely connected to all the equipment we deliver, because this gives the customer data for the assistant decision* support. *This is one of the main strategies for the company to succeed.*"

## 5. Discussion and conclusions

### 5.1. Theoretical contribution

Manufacturers are rapidly adopting smart autonomous solutions as they transition toward AI-enabled product–service systems – a transition that is often referred to as digital servitization (Coreynen et al., 2017; Frank et al., 2019; Kohtamäki et al., 2019; Vendrell-Herrero et al., 2017). This transition emphasizes the role of AI as a source of potential competitive advantage when creating novel product–service systems. This study contributes to the existing digital servitization literature in two significant ways. First, the study incorporates artificial intelligence into product–service systems. A proposed path model shows how relevant technologies, ecosystem partnerships and AI-enabled PSS co-evolve over time. Second, the study outlines managerial practices for strategizing, evangelizing, and routinizing AI-enabled PSS, offering some guidance for managers on how to facilitate the development of AI-enabled PSS.

As the first theoretical contribution, this study integrates AI with product–service systems. The study identifies a path model that encompasses AI-enabled PSS, AI-related PSS technologies, and AI-related PSS ecosystem partnerships. These elements are recognized as critical for the transition to autonomous solutions. The findings offer important insights into AI-enabled product–service systems, outlining a step-by-step approach for manufacturers to develop these systems (Ayala et al., 2025; Sjödin et al., 2020) based on the case study. The case study analyzed the development paths related to AI-enabled PSS, AI-related PSS technologies, and AI-related PSS ecosystem partnerships. Without these technological innovations and the development of industrial partnerships, achieving AI-enabled PSS would be impossible. The three layers are interdependent and the managerial practices outlined are required to navigate between the layers effectively.

As the second theoretical contribution, and building on the practice theory (Kohtamäki et al., 2022a,b; Whittington, 2006), we identify managerial practices for strategizing, evangelizing, and routinizing AI-enabled PSS. Strategizing AI involves defining a clear strategic direction and means that guide the organization toward AI-enabled product–service systems. This approach emphasizes growth, disrupting the value chain, and diversifying into digital solutions, such as offshore wind and aquaculture. Evangelizing AI goes beyond simply adopting technology, fostering a culture of innovation and adaptability, enabling the organization to embrace current AI capabilities, and actively shaping a future where AI is integral to the firm's organizational identity. Lastly, routinizing AI entails legitimizing its role, shaping the internal discourse, prioritizing customer insights, and allocating resources for continuous improvement. This establishes a foundation for a future where AI is a core component of the organization and its business strategy. Arguably, these strategic practices enable firms to engage in digital servitization and autonomous solutions to steer technological innovation and sustainable growth through a complex organizational transformation.

### 5.2. Managerial implications

The study has some relevant contributions that can help managers to navigate the transition toward AI-enabled product–service systems. First, the timeline illustrates the case company's journey toward AI-enabled PSS, technologies, and ecosystem partnerships, offering insights into the necessary steps required to implement this transition. This model may help organizations and managers to identify the types of product–service systems, technologies, and ecosystem partnerships they need to promote innovation. The study highlights the importance of the resources, activities, and processes in the timeline as assets that managers can use when trying to understand their digital servitization journeys. Moreover, when these activities are contextualized in time, the order of the activities is underlined, and the activities can be better aligned. This may seem obvious but is often forgotten when implementing strategy. Thus, this processual look of activities can help to plan the digital servitization development roadmap to support the implementation (Kohtamäki et al., 2021).

Second, managers play an important role in driving the change toward AI by utilizing the managerial practices of strategizing, evangelizing, and routinizing AI. These practices highlight three interconnected aspects of managing innovation in product–service systems: establishing a long-term direction, achieving a shared understanding of the vision and the strategic means to achieve it, adopting the AI as a technology, while creating an organizational culture to develop the necessary capabilities, but also then creating routines that legitimize the use AI-enabled product–service systems. Creating a strategy and culture enhance product–service systems through the use of AI is not an easy task, and should be prioritized by managers. Meaningful managerial effort is required to find the required market access and to scale up the AI-enabled PSS. It may be that the decision to move towards AI-enabled PSS is all-in or nothing.

Third, navigating between the different layers of the timeline is critical for managers. They should not only coordinate the single activities or layers but also foster interaction between the layers and the activities within. Therefore, managers should pay attention not only to strategic practices at the top-management level but also promote micro-level investment into technologies and related activities, and their alignment with the process of ecosystem orchestration (Kohtamäki et al., 2019; Thomson et al., 2022). Moving across the organizational boundaries may necessitate an open strategy approach (Whittington, 2019).

Fourth, managerial practices consist of sayings and doings. Therefore, it is important to align the sayings between the managers in different positions so that these sayings start actually shaping the doings. Managers should be consistent in their approach to the narratives they use and align them with the "practical" practices to foster AI-enabled PSS.

### 5.3. Limitations and suggestions for future servitization research

As with any research, this study has its limitations. First, it is a single case study conducted with one of the leading solution providers developing autonomous solutions. Obviously, the specific context of the single case limits the generalizability of the findings. Second, navigating the shift between micro and macro perspectives can be challenging because, while the firm is the primary unit of analysis, we had to include activities at the level of product–service systems, technologies, and ecosystem partnerships. In addition, the study examines the practices used to manage the transition toward AI-enabled PSS. Therefore, several issues needed to be addressed. However, this was feasible given the single case study context that allows for better control of various factors and their interactions. Third, studying the integration of AI into product–service systems presented a complex challenge. Certainly, further research would be beneficial as AI continues to evolve in product–service systems and manufacturing servitization domains.

As a conclusion, this study demonstrated the novel interplay between AI-enabled PSS, AI-related PSS technologies, and AI-related PSS ecosystem partnerships, in the company's transformation toward AI-enabled product–service systems. Even more importantly, the study identified the managerial practices needed during the transformation.

## CRediT authorship contribution statement

**Marko Kohtamäki:** Writing – original draft, Visualization, Supervision, Project administration, Formal analysis, Conceptualization. **Thomas Brekke:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Rimsha Naeem:** Writing – review & editing, Writing – original draft, Conceptualization. **David Sjödin:** Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition, Formal analysis, Conceptualization. **Vinit Parida:** Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition, Formal analysis, Conceptualization.

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## Appendix

*Appendix 1. Illustrative examples of quotations demonstrating data structure on evolution of capabilities (see Figs. 1 and 3)*

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| AI-related PSS ecosystem partnerships | Initiating digital partnerships<br>Strategic acquisitions of AI-enabling technologies by mergers, joint venturing, and spin-out:<br>*"Our company is fairly big because we bought another marine company, and it was incorporated more than a year ago. So, we now have everything from thruster, propels, and up to the ship and energy, surveillance and management service systems."*<br>Partnering with domain knowledge provider:<br>*"What we have tried to do is that our company is a technology provider, and the partner is coming with the operational and domain knowledge. So, they are giving us the requirements from the operator side, and then we are transforming that knowledge into products, solution, and systems functionalities."*<br>Testing disruptive technologies (solutions) with new customer:<br>*"Both company Y and A, who have been the first movers in this, are not coming from the maritime domain. They would like to solve grand logistical challenges."* | Developing an innovation ecosystem to commercialize AI-enabled services<br>Initiating joint research and certification programs with universities and partners:<br>*"So, we are working closely with Norwegian Maritime Authorities, the class authorities, and some of the education communities, where we are looking at what are the implications for legislation and staffing of the shore remote control center."*<br>Developing legal and regulatory framework:<br>*"IMO has the ball and has started a scoping exercise, but we all know it can take some time. Right now, we are focused on Norway having the first commercial 100 % autonomous vessel being built, the Yara-Birkeland, and that is pushing the Norwegian authorities to make some decision."*<br>Verifying value offerings with disruptive customer:<br>*"There is a new wave of cooperation because the shipping industry understands that we can't do this alone. That is new because we used to do everything inside on our own. This digital disruption leads us to wake up and find partners outside shipping to get to this next level of digitalization."* | Scaling an innovation ecosystem<br>Identify grand logistic challenges:<br>*"The new customers are the first movers, as they do not come from the maritime domain. They are aiming to solve logistical challenges they might have. Our customers are aiming to move goods from the road to the waterways. "*<br>Identify value pools and digital marketplace offerings:<br>*"What values are we tending to get from these players? What I would like to identify is how we can increase the overall value offering to our partners."*<br>Orchestrating wider value chain offerings:<br>*"Offshore activity, trade fleet activity, and total logistics become more digitalized. With digitalization you can put logistics in a broader view, such as combining road transport, reloading, and vessel transport. This is more dependent on digital solutions and remote operation centers, where people with overview and competence can use data for fleet management and advanced logistic operation."* |
| **AI-enabled PSS** | **Verifying value offerings with disruptive customer**<br>Data analytics for optimalization of vessel and fleet management services:<br>*"From our side, the software is when the brainwork comes in. So that is the smartness, and the hardware is just the enabler to perform that functionality. So, we are shifting a bit away from hardware focus towards what kind of benefits, services, kinds of functionalities, what kind of added value you are getting from the software."*<br>Control, monitoring, maintenance, and prediction services:<br>*"The fuel, the maintenance, crewing part, risk part, everything. Compliance as well. If we have sensors onboard the ship and have it connected, we can transfer a lot of valuable data for control, monitoring,* | **Developing integrated optimization solutions**<br>Convergence of structured data for software analytics and remote decision making by vessel insight:<br>*"However, digitalization requires access to quality data from vessels, and it's this part of the puzzle that vessel analytic delivers. Vessel analytic is the infrastructure service that helps customers access structured data. This will make digitalization accessible to a wider user-base and help the maritime industry to be more sustainable in both economic and environmental terms."*<br>Auto docking and advanced maneuvering services:<br>*"Autonomous unmanned vessels need docking solution and technology that supports the arrival of* | **Creating AI-enabled services and autonomous solutions**<br>Developing self-assessment, control, monitoring, and predictions systems services for remote operational and fleet management:<br>*"When we are talking about product it could be one individual product, it could be a suite of products tightly integrated to a system solution, or it could be a large system of systems things, connected to that. It could be for energy savings, for navigational part, it can be for connectivity, or on shore control center (ROC). My job is to extract the requirements from all these different segments and harmonize them to a set of requirements, prioritize them with our products department, and see what creates revenue for us."*<br>Environment and health management systems: |

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| | *and predictions."*<br>Remote and digital analytic systems service:<br>*"As I see it, the value or remote operation center (ROC) is the many levels of services and products that can be in the same offering, such as fleet monitoring. This is important as it can optimize and monitor the fleet and make cost savings possible as one person can control multiple vessels and reduce manning on the vessel."* | *the vessel, docking time, and departure. Connectivity is important for the docking. Now, it has become a product area and a technology area in our company, that creates more attention."*<br>AI-enabled energy and fuel optimization services:<br>*"Once we can connect everything we have in our portfolio and put that information in one platform... … It is all about sharing data and using it for something valuable. To interfere, do operation or condition monitoring, fuel advisory and such."*<br>Developing digital platform marketplace:<br>*We have third parties, which can build their application on top of this and be a part of the platform marketplace, and they can buy the application.*<br>*It is quite like the iPhone and App Store."* | *"We got energy and health monitoring systems, propulsion and machinery, and we sort of got operations that include everything of the automation system and these things. So, you take the responsibility of a complete delivery."*<br>Safety and risk control systems:<br>*"Then you have these heavy shell transport with a lot of tank boats with a lot of floating goods that move around the world on large boats, large values, and they can have a huge effect on the environment if accidents happen. So, they have another motivation that lies in navigational security."* |
| **Digital technology development for AI-enabled PSS** | **Building digital infrastructure capabilities**<br><br>Develop and test remote shore control center:<br>*"So, we define it as a remote operation center, not a remote-control center or shore control center. It does not have to be on shore, and it does not have to be controlled. In a remote operation center, you could have one or man many remote operation workstations. So that's where the operator will be sitting, and a workstation can be used for monitoring, supervision, intervention of a fleet of vessels, or it could be used for direct control of one vessel."*<br>Secure data sharing and standardization of data from advanced sensors, robotics, and video systems:<br>*"I think, if you take a holistic view, all vessels are controlled by a certain control system. If you don't have a control system with an extended digital arm, we will be out of business. It is very important for us as a company to have solutions which are closely connected to all equipment we deliver, because this gives the customer data for the assistant decision support. This is one of the main strategies for the company to succeed."*<br>Electrification, battery and charging systems:<br>*"Our system takes the vessels to the dock, to the ramp and moors it, establish charging, ensures the right charging flow and we have this ramp that is established to get goods on and off. We are the system integrator and make sure that all these technologies fit together"*. | **Developing reliable and advanced systems technologies**<br>Integration of multi-functional systems, such as dynamic position, sensors and robotics, with software analytics (vessel insights) and digital twins:<br>*"The phase we are in now is a scaling phase. We would like the infrastructure to be on a lot of vessels, and we have a target for several customers which we are working with. When a lot of vessels are sending data to shore and the different needs from the different customers becomes clearer, we will have a lot of functionalities, a lot of applications in the marketplace."*<br>Testing autonomous and zero-emission vessel:<br>*"The components needed in an autonomous vessel has been tested for years, it is 40 years ago. It has been tested in many other areas such as using camera systems used in the airline industry, and the defense industry. What is new is putting those technologies together and creating a fusion of sensors, cameras, and an autonomy brain on the vessel, that can replace human situational awareness."* | **Artificial intelligence development**<br><br>Offering autonomous end zero emission vessels with support from remote shore control center:<br>*"A remote operation center is able to operate multiple vessels. So, the fleet perspective, as I see it, is a necessity for having a sound business case."*<br>Vessel insights data infrastructure offerings:<br>"*We see an increase in ship operators or owners who want to have control over their fleet. So, you have the digital layer that provides them with data and information. They (customers) are looking at what type of information is relevant. It is not about getting all the data to land, because that is costly. It is more about identifying what creates value for that operator and what it takes to enable that. That is where vessel insight comes into place, you can start doing analyses of the vessel performance, or a fleet of vessels and compare them with other vessels."* |

*Appendix 2. Illustrative examples of quotations demonstrating phase evolution of the timeline (Fig. 5)*

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| Digital technology development for AI-enabled PSS | Building digital infrastructure capabilities<br><br>Develop and test remote shore control center:<br>*"So, we define it as a remote operation center, not a remote-control center or shore control center. It does not have to be on shore, and it does not have to be controlled. In a remote operation center, you could have one or many remote operation workstations. So that's where the operator will be sitting, and a workstation can be used for monitoring, supervision, intervention of a fleet of vessels, or it could be used for direct control of one vessel."*<br>Secure data sharing and standardization of data from advanced sensors, robotics and video systems:<br>*"I think, if you take a holistic view, all vessels are controlled by a certain control system. If you don't have a control system with an extended digital arm, we will be out of business. It is very important for us as a company to have solutions which are closely connected to all equipment we deliver because this gives the customer data for the assistant decision support. This is one of the main strategies for the* | Developing reliable and advanced systems technologies<br>Integration of multi-functional systems such as dynamic position, sensors and robotics, with software analytics (vessel insights) and digital twins:<br>*"The phase we are in now is a scaling phase. We would like the infrastructure to be on a lot of vessels, and we have a target for several customers which we are working with. When a lot of vessels are sending data to shore and the different needs from the different customers becomes clearer, we will have a lot of functionalities, a lot of applications in the marketplace."*<br>Testing autonomous and zero-emission vessel:<br>*"The components needed in an autonomous vessel has been tested for years, it is 40 years ago. It has been tested in many other areas such as camera systems used in the airline industry, and the defense industry. What is new is putting those technologies together and creating a fusion of sensors, cameras, and an autonomy brain on the vessel that can replace human situational awareness."* | Artificial intelligence development<br><br>Offering autonomous end zero emission vessels with support from remote shore control center:<br>*"A remote operation center is able to operate multiple vessels. So, the fleet perspective, as I see it, is a necessity for having a sound business case."*<br>Vessel insights data infrastructure offerings:<br>"*We see an increase in ship operators or owners who want to have control over their fleet. So, you have the digital layer that provides them with data and information. They (customers) are looking at what type of information is relevant. It is not about getting all the data to land because that is costly. It is more about identifying what creates value for that operator and what it takes to enable that. That is where vessel insight comes into place, you can start doing analyses of the vessel performance, or a fleet of vessels and compare them with other vessels."* |

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| | *company to succeed."* Electrification, battery and charging systems: *"Our system takes the vessels to the dock, to the ramp and moors it, establish charging, ensures the right charging flow, and we have this ramp that is established to get goods on and off. We are the system integrator and make sure that all these technologies fit together."* |

*Appendix 3. Illustrative examples of quotations demonstrating the evolution of managerial practices in the three phases of preparing, conceptualizing, and industrializing (Figs. 3–5)*

| | Strategizing of AI-enabled PSS solutions | Evangelizing AI-enabled PSS solutions | Routinizing AI-enabled PSS solutions |
|---|---|---|---|
| **Phase 1. Preparing the company for advanced form of digital PSS** | Visioning growth of AI-based business *"I think you will find that we are looking at this as a huge opportunity, of course to do better business, while ship owners are still looking at it as a possibility to understand and elaborate for themselves, what will be the future shipping." "We believe that the situation for delivering that kind of equipment will be different from what it is now because the need for service, maintenance, and so on will be to a larger extent than today."* | Crafting the AI narrative *"If you imagine your old car, anyone could do a service on that. You could do a lot yourself, but if you look into a new car, you can't do anything. What you get is a lot of information through the system, the displays inside the car, how it behaves, and when it needs service and so on, but you can't do anything yourself. That is also what we see happening on board ships now." "One of the things that has been a mantra in the company has been that you will never be competitive by using yesterday's technology. So, it's that extreme forwardness. Being at the front, that's where it's fun to be."* | Legitimizing AI development practice *"When a lot of vessels are sending data to shore and the different needs from the different customers become clearer, we will have a lot of functionalities, a lot of applications in the marketplace. This will be an evolution in the coming year." "Now we start talking about integrated systems. And one of the important things is to take a position as the preferred system integrator supplier."* |
| **Phase 2. Conceptualizing advanced form of digital PSS** | Disrupting the value system for AI *"There is a new way of cooperation because the shipping industry understands that we can't do this alone. That is new because we used to do everything on our own. This digital disruption leads us to wake up and find partners outside shipping to get to this next level of digitalization." "One of the things I experience with the maritime market is that it is very conservative. And one of the interesting things is when new actors come in and become players. Also suddenly, there are starting to be completely different customers out there than is traditionally the case, large industrial or commercial operators who need one or another service and who then choose to go in new directions. And I find that very exciting and it's incredibly challenging."* | Accessing market with AI-enabled PSS *"It is a long period of testing out in real life scenarios with crew onboard and gradually allowing the automated systems to take over more and more of the operation, until the legislative bodies feel satisfied that it is a safe operation, and they will grant approval for the vessel." "We started playing around with which parts of these functions will make up the digital captain, the digital chief, the digital super-attendant etcetera. That puts different requirements to the connectivity solution."* | Systematic use of customer feedback *"Because digitalization as we have experienced comes down to domain knowledge. It is so important to know what kind of process on board the vessel, or what kind of culture the company has, and you need to mix this together with the technology. It is quite difficult for us to have domain knowledge on any single process or any single vessel type, or every single operation. It is a journey together with the customer." "It's like when Strava is making an update, it happens with all users globally. And that's how we work. We get constant feedback from customers, and if one customer is giving us valuable feedback that we need some product enhancements it benefits all customers. So, product is constantly updating, its constantly changing."* |
| **Phase 3. Industrializing of autonomy** | Repositioning for AI *"People are used to selling service agreements and propellers. Selling digital solutions is a whole other industry." "It will be evolving, I think, if you take a holistic view, all vessels are controlled by a certain control system. If you don't have a control system with an extended digital arm, we will be out of business. It is very important for our company to have solutions which are closely connected to all equipment we deliver because this gives the customer data for the assistant decision support."* | Scaling-up AI-enabled PSS *"Companies who have been the first movers in this (PSS solutions) are not coming from the maritime domain, they are looking to solve grand logistical challenges. They are moving goods from the road to the waterways." "… what we need to target is early adopters, people like ship owners are starting to understand that they need to do something, but they are a little unsure of how. So, it is very natural for them to cooperate with us, because our value propositions help the customer to connect the vessels so that people on shore understand the status of the vessels."* | Industrializing AI *"The face we are in now is a scaling faze. We would like the infrastructure to be on a lot of vessels. When a lot of vessels is sending data to shore and the different needs from the different customers becomes clearer, we will have a lot of functionalities, a lot of applications in the marketplace." "We will also see that the customers would like to have digital twins of their vessels or rigs. This will give them a lot of publicity, and publicity creates curiosity. This will be an evolution in the coming year."* |

## Data availability

The authors do not have permission to share data.

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**Marko Kohtamäki** (Ph.D.) is a Professor of Strategy at the University of Vaasa, and an adjunct professor at the Luleå University of Technology. He has been included in the Stanford list amongst the highest cited 2 % of researchers in his field. Kohtamäki takes special interest in digital servitization and product-service systems, strategic practices, business models, Artificial Intelligence, business intelligence and strategic alliances in technology companies. Kohtamäki has published over 100 articles in distinguished international books and journals such as Strategic Management Journal, International Journal of Operations and Production Management, International Journal of Management Reviews, Strategic Entrepreneurship Journal, Industrial Marketing Management, International Journal of Production Economics, Long Range Planning, Technovation, Journal of Business Research, amongst others.

**Thomas Brekke (Ph.D)** is an Associate Professor in innovation and entrepreneurship at the USN School of Business. Thomas has his PhD. from Norwegian University of Science and Technology (NTNU). Brekke conducts research on topics such as regional and industrial transformation, digital servitization, business models, innovation, and entrepreneurship from the management perspective. Brekke has published several articles in distinguished international books and journals such as Review of Managerial Science, Journal of Manufacturing Technology Management, Industry and Higher Education, International Regional Science Review, Entrepreneurship & Regional Development, European Planning Studies.

**Rimsha Naeem** (MSc., MPA) is a Doctoral Researcher at the University of Vaasa, Finland. During her DSc. at University of Vaasa, Naeem focuses on Artificial Intelligence, Product Service Innovation, Digital Servitization, and Digital Transformation among technology companies.

**David Sjödin** is an associate professor of entrepreneurship and innovation at Luleå University of Technology, Sweden and a professor of entrepreneurship and innovation at University of South Eastern Norway. He conducts research on the topics of servitization, AI and digitalization, innovation ecosystems, and business model innovation in collaboration with leading global firms and regularly consults industry and government. He has published 50+ papers in distinguished international journals, including California Management Review, Long Range Planning, Journal of Product Innovation Management, Journal of Business Research, Industrial Marketing Management, Technovation and others. He is the recipient of multiple awards for his research, including the Entrepreneurship Forum Young Researcher Award 2018 for his research on the servitization of industry.

**Vinit Parida** (Ph.D.) is a professor at entrepreneurship and innovation at Luleå University of Technology, Sweden. His research interests include servitization, business models, open innovation, and organizational capabilities. He has published more than 100 journal articles, including articles in *Strategic Management Journal, Journal of Management Studies, Long Range Planning, Industrial Marketing Management, Production and Operations Management, Journal of Cleaner Production*, and others.