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Rethinking Engineering Asset Management: Leveraging Digitalization and Agile Methodologies for Enhanced Operational Efficiency

PhD dissertation

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Preface

This dissertation is submitted as a summary of a collection of scientific articles. Therefore, it is not a monography but a collection of five published or publishable papers. This presentation describes the relation between the publications and how each contribute to the overall PhD project, as described in the "Rules and guidelines for the PhD degree programme" of 15/11/2023 by Aarhus BSS Graduate School, Aarhus University[1].

As the included papers are to stand on their own, the reader of this dissertation will likely experience repeating points and positionings, especially in the introductory parts of the publications.

Please notice that the final papers have been peer-reviewed by editors and reviewers of the different journals and conferences these are published at. In the process these papers, have been shaped to adhere to the conferences and journals, requirements, customs and formats.

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[1] https://bss.au.dk/en/research/phd/rules-and-regulations

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Executive summary

This executive summary provides an overview of a dissertation that addresses the challenges and uncertainties in industry through the integration of Engineering Asset Management, Agile methodologies, and Digitalization. The empirical playground for the dissertation was centered on the Danish industry. EAM emerged in the mid-2000s to guide the interdisciplinary management of physical assets and gained steady interest in the following decades. However, the principles of EAM have largely been codified within the ISO 5500x series of standards on asset management. Yet, despite asset management global recognition and increasing attention, there remains a gap in the literature concerning the integration of Agility and Digitalization within Asset Management. This dissertation focuses on exploring this intersection and developing new frameworks and artifacts to enhance asset management practices, thus, advancing both theoretical understanding and practical application in the field.

The dissertation is guided by one main research question and three supportive questions:

Main RQ: How can Engineering Asset Management through integration with agility and digitalization, enable better navigation of an organizations strategic, operational and technological demands?

RQ1: What does a conceptual and practical framework for agile in the context of EAM/AM look like?

RQ2: What does a conceptual and practical foundation for Digitalization in the context of EAM/AM look like?

RQ3: How can an applied EAM intervention that builds on agile and digitalization, enable AM compliance and the advancement of operational goals and objectives?

The dissertation answers the three supportive questions over three chapters (2-4), each chapter consisting of either one or two papers, that are either submitted or published in conference proceedings or journals. Chapter 1, introduces the structure of the dissertation, provides argument and some theoretical background for the problems examined, presents the research gaps and methodological considerations.

Chapter 2 addresses the theoretical and practical reality of agility as a foundational concept within industrial and developmental contexts, correlated to asset management, explored through two publications. The first publication examines and determines core processes of agile methodologies, control, work, and knowledge management, highlighting their importance for effective leadership and governance. The second publication redefines industrial agility as a strategic capability, tailored to meet the specific demands of the sector, enabling organizations to adapt to market dynamics and maintain competitive performance. Additionally, an artifact was developed to link agile methodologies with engineering asset management, emphasizing the transformative potential of agility in managing projects, assets, and operations within industrial ecosystems.

Chapter 3 addresses the theoretical and practical foundation for digitalization in the context of Asset Management. The central findings related to RQ2 are drawn from two key publications. The first examines the critical role of data maturity in shaping maintenance strategies, highlighting the importance of aligning digitalization efforts with organizational asset maintenance objectives. Despite the recognized benefits of digitalization, the second publication reveals a lag in adoption across organizations in Denmark, with a range of digital maturity levels observed. This variation indicates the need for a stronger emphasis on fundamental digitalization aspects, particularly in relation to foundational activities. Addressing inhibitors and drivers such as cost, complexity, and skill levels is essential for successful digital transformation. Ultimately, the findings suggest that optimizing foundational activities before advancing digitalization will lead to more sustainable and effective digital strategies, enhancing operational efficiency and value creation.

Chapter 4 addresses the exploration of how an applied Engineering Asset Management intervention, utilizing agile methodologies and digitalization, can enhance compliance and advance operational

objectives. RQ3 centers on the development of an artifact that incorporates these principles, revealing a gap in the case company's approach to smaller projects, which often lack adherence to certification requirements. The proposed framework addresses this by ensuring comprehensive compliance and optimizing asset performance, through the use of among other things, risk management tools and backlog-esque principles. Through a detailed examination of the case company's challenges, including digital tool integration, sustainable practices, and skill shortages, the framework emphasizes the need for transparent and formalized internal processes. The findings highlight the evolving role of EAM in industrial agility and digitalization, underscoring their importance in developing strategies that enhance compliance, efficiency, and strategic alignment, ultimately securing a competitive edge in a complex market landscape.

The dissertation concludes with Chapter 5, which discusses the findings, methodologies, and the findings relevance for the industry and academia. This final chapter correlates and synthesizes the findings and demonstrates the implications for future research and the practical application to established AM practitioners and curious companies looking into the subject matter.

This dissertation has contributed several novelties to the discussion on AM, through the lens of agility and digitalization. Specifically, these novelties emerged from the research on integrating agile methodologies and digitalization within Asset Management. The initial exploration identified a gap in the literature, addressed by developing two significant contributions: a novel framework for industrial agility and a model that correlates data maturity with maintenance strategy. The research also introduced an framework that integrates agility and digitalization principles, enhancing compliance and operational efficiency in asset management. Furthermore, the study offers a unique assessment of digital maturity within the Danish industry, underscoring the practical relevance of theoretical insights. The work advances a more integrated and academic understanding of EAM through a pragmatic approach that bridges theoretical concepts with industrial practice.

Resumé

Dette resumé præsenterer et kortfattet overblik over en afhandling, der udforsker udfordringer og usikkerheder i industrien, gennem integration af Engineering Asset Management (EAM), agile og digitaliserings metoder. Afhandlingens empiriske fokus var centreret omkring den danske industri. EAM opstod i midten af 2000'erne for at vejlede den tværfaglige forvaltning af fysiske aktiver og har fået stigende interesse i de efterfølgende årtier. EAM-principperne er dog i høj grad blevet kodificeret inden for ISO 5500x-serien af standarder for Asset Management. På trods af global anerkendelse og øget opmærksomhed på asset management er der stadig et hul, med hensyn til integrationen af agility og digitalisering inden for Asset Management. Denne afhandling fokuserer på at udforske dette krydsfelt og udvikle nye rammer og artefakter for at forbedre asset management-praksisser, hvilket både fremmer teoretisk forståelse og praktisk anvendelse inden for området.

Afhandlingen er styret af ét hovedforskningsspørgsmål og tre understøttende spørgsmål:

Hovedspørgsmål: Hvordan kan Engineering Asset Management gennem integration med agilitet og digitalisering muliggøre bedre navigation af en organisations strategiske, operationelle og teknologiske krav?

Spørgsmål 1: Hvordan ser et teoretisk og praktisk udgangspunkt for agilitet ud i EAM/AM-sammenhæng?

Spørgsmål 2: Hvordan ser et teoretisk og praktisk udgangspunkt for digitalisering ud i EAM/AM-sammenhæng?

Spørgsmål 3: Hvordan kan en anvendt EAM-intervention, der bygger på agile metoder og digitalisering, muliggøre AM-compliance og fremme operationelle mål og målsætninger?

Afhandlingen besvarer de tre understøttende spørgsmål over tre kapitler (2-4), hvor hvert kapitel består af enten en eller to artikler, som enten er indsendt eller offentliggjort i proceedings fra konferencer eller i tidsskrifter. Kapitel 1 introducerer afhandlingens struktur, argumenterer for og giver teoretisk baggrund for de undersøgte problemstillinger, præsenterer uafklarede spørgsmål i den eksisterende litteratur samt metodologiske overvejelser.

Kapitel 2 behandler den teoretiske og praktiske virkelighed af agilitet som et grundlæggende koncept inden for industrielle og udviklingsmæssige sammenhænge, relateret til asset management, undersøgt gennem to publikationer. Den første publikation undersøger og fastlægger kerneprocesser i agile metoder, kontrol, arbejds- og videns styring, og understreger deres betydning for effektiv ledelse og styring. Den anden publikation definerer industriel agilitet som en strategisk kapabilitet, skræddersyet til at imødekomme sektorens specifikke krav, hvilket gør det muligt for organisationer at tilpasse sig markedsdynamik og opretholde konkurrencedygtig ydeevne. Derudover blev der udviklet et artefakt til at forbinde agile metoder med engineering asset management, hvilket understreger agilitets transformative potentiale i håndteringen af projekter, aktiver og operationer inden for industrielle økosystemer.

Kapitel 3 behandler de teoretiske og praktiske udgangspunkter for digitalisering i sammenhæng med Asset Management. De centrale fund relateret til spørgsmål 2 er trukket fra to nøglepublikationer. Den første undersøger data modenhedens afgørende rolle i udformningen af vedligeholdelsesstrategier og fremhæver vigtigheden af at tilpasse digitaliseringsindsatser med organisationens vedligeholdelsesmål for aktiver. På trods af de anerkendte fordele ved digitalisering afslører den anden publikation en forsinkelse i adoption på tværs af organisationer i Danmark, med en række forskellige digitale modenhedsniveauer observeret. Denne variation indikerer behovet for en stærkere vægt på grundlæggende digitaliseringsaspekter, især i relation til grundlæggende aktiviteter. Det er essentielt at adressere hæmmere og fremmere som omkostninger, kompleksitet og færdighedsniveauer for en vellykket digital transformation. Endelig foreslår fundene, at optimering af de grundlæggende aktiviteter før digitalisering initiativer, vil føre til mere bæredygtige og effektive digitale strategier, der forbedrer operationel effektivitet og værdiskabelse.

Kapitel 4 udforsker, hvordan en anvendt Engineering Asset Management-intervention, der udnytter agile metoder og digitalisering, kan forbedre compliance og fremme operationelle mål. Spørgsmål 3 fokuserer på udviklingen af et artefakt, der inkorporerer disse principper, og afslører en mangel i case-virksomhedens tilgang til mindre projekter, der ofte mangler compliance af certificeringskrav. Det foreslåede rammeværk imødekommer dette ved at sikre compliance og optimere asset ydeevne gennem bl.a. brugen af risikostyring og backlog-agtige værktøjer. Dette gøres gennem en detaljeret undersøgelse af case-virksomhedens udfordringer, herunder integration af digitale værktøjer, bæredygtige praksisser og mangel på kompetencer, hvilket understreger behovet for transparente og formaliserede interne processer. Fundene fremhæver EAM's udviklende rolle i industriel agilitet og digitalisering, og understreger deres betydning i udviklingen af strategier, der forbedrer overholdelse, effektivitet og strategisk tilpasning, hvilket i sidste ende sikrer en konkurrencemæssig fordel i et komplekst marked.

Afhandlingen afsluttes med kapitel 5, der diskuterer resultaterne, metoderne og fundenes relevans for industrien og akademia. Dette sidste kapitel korrelerer og syntetiserer fundene og demonstrerer implikationerne for fremtidig forskning og praktisk anvendelse for etablerede AM-praktikere og nysgerrige virksomheder, der ønsker at udforske emnet.

Denne afhandling har bidraget med flere nye elementer til diskussionen om AM gennem en linse af agilitet og digitalisering. Specifikt er disse elementer opstået fra forskningen i integration af agile metoder og digitalisering inden for Asset Management. Den indledende undersøgelse identificerede et hul i litteraturen, der blev adresseret ved at udvikle to væsentlige bidrag: en ny ramme for industriel agilitet og en model, der korrelerer datamodenhed med vedligeholdelsesstrategi. Den udførte forskning introducerede også en ramme, der integrerer agilitet- og digitaliseringsprincipper, hvilket forbedrer overholdelse og operationel effektivitet i asset management. Desuden tilbyder det udførte studie en unik vurdering af digital modenhed inden for den danske industri, hvilket understreger den praktiske relevans af de teoretiske indsigter. Arbejdet fremmer en mere integreret og akademisk forståelse af EAM gennem en pragmatisk tilgang, der forbinder teoretiske begreber med industriel praksis.

1 Chapter- Introduction

This chapter introduces the topics and research gaps of the dissertation, presents the research questions and methodology, and finishes with an overview of the conducted research.

1.1 Background, research gap and positioning

The following section is structured as follows. First, an introduction to key concepts that are necessary for the understanding of the theoretical scope of the dissertation. The clarification of the key concepts is not meant to be a comprehensive overview of the literature on the topic, but to serve as a guide for the reader to gain perspective on the dissertation. The chapters in the dissertation include more detailed literature. With the literary context in mind a series of research gaps will be presented. And lastly a short overview of the positioning of the research within the context of the key concepts and the research gaps will be detailed.

1.1.1 Engineering Asset Management and Asset Management

Engineering Asset Management (EAM) emerged conceptually as a derived management methodology of Asset Management (AM) in the mid 2000's, with EAM concerning the management of Physical assets, as opposed to financial assets (Amadi-Echendu *et al.*, 2010; Amadi-echendu *et al.*, 2010). EAM was conceptually created as a response to the need for interdisciplinarity in the management of the large-scale asset investment both in the private and public sector (Ruitenburg, Braaksma and Van Dongen, 2014). With the mid 2000's lacking clear direction regarding Asset Management definition and the interplay with the "operational and maintenance" part of the organization, the proposal of EAM or Physical asset management is a response to that (Amadi-Echendu *et al.*, 2010). However, the subsequent Industrial standards from 2014 and updated in July 2024, ISO 5500x, published by the International Organization for Standardization (ISO), on Asset management have since incorporated a significant part of the concerns covered by EAM. Therefore, AM as defined by the ISO 5500x series of standards, *is the application of coordinated activities in an organization to create value on behalf of an asset* (ISO 55000 series, 2014).

The express focus on the concept of *value* is at the core of AM, however, no express definition of value can be found in the literature, with a specific definition specifically being dependent on the company's purpose (Roda *et al.*, 2016). However, it is widely acknowledged that the realization of value is contingent upon a company's ability to balance risks, opportunities, costs, and benefits in the procurement, deployment, operation, maintenance, and disposal of assets (Lima and Costa, 2019). Others have built upon this definition and determined that AM is a global process through which value is added or preserved to a company, centered on a managerial model that involves changes in strategies, technologies, resources, risk management, and change management in the involved personnel (García-Gómez *et al.*, 2021). Thus, the operational considerations pertaining to EAM, by and large are covered by the 5500x series.

Accordingly, ISO 5500x embraces interdisciplinarity and the vertical and horizontal alignment that is needed for successful AM integration and application, albeit through a highly interpretable set of guidelines. Erguido et al. (2022) exemplifies five domains that affect the enhancement of an assets value within AM; *Life cycle management, Risk-based management, the alignment between organizational and asset management objectives, maintenance management* and *Logistics support and procurement.* Thus, to improve the decision process within the management of physical assets, capabilities should be developed within these five domains (Erguido *et al.*, 2022). Incidentally, AM does not necessarily propose something new, but it does contextualize the management of assets into a new language and a set of guidelines that is set to create and preserve the value of the assets (Polimac and Polimac, 2016), according to the objectives of the organization. AM enables and supports the lifecycle perspective of the asset, and considering that physical asset (utilities, transportation, manufacturing, etc.) are everywhere, securing this ongoing value in increasingly demanding positions is critical (Alsyouf *et al.*, 2018).

Further, with the 5500x series being regarded as state-of-the-art in industry standards on AM and are employed by numerous organizations globally, focusing exclusively on EAM would be insufficient (ISO, 2025). The 5500x series establishes the benchmark against which organizations involved in AM measure their performance against, both for certification purposes and theoretical comprehension (Gavrikova, Volkova and Burda, 2020). According to ISO, an asset encompasses everything that generates value within an organization, including tangible, intangible, financial, and non-financial assets (ISO 55000 series, 2014). Whereas the distinction from EAM on Engineering assets, specifically, refer to physical assets designed and engineered to create business value for an organization through strategically acquired capabilities and resources (Hastings, 2021, p. 6).

1.1.2 Agility and EAM

Agility and the underlying principles and management approaches within, is considered a leading development model, proven successful within especially manufacturing, product- and software development (Serrador and Pinto, 2015; Gunasekaran *et al.*, 2019). Agile manufacturing emerged in the 1990s and centers on the rapidly changing requirements that exist within a given market, including both volume and variety, meaning that the manufacturing environment should be scalable and changeable (Nagel, Dove and Preiss, 1991; Esmaeilian, Behdad and Wang, 2016). Agile software development adheres to the same principles of adaptability, costumer centricity and flexibility, with the Agile manifestos from 2001, cementing these in four values (Beck *et al.*, 2001).

- *Individuals and interactions over processes and tools*
- *Working software over comprehensive documentation*
- *Customer collaboration over contract negotiation*
- *Responding to change over following a plan.*

Building on this, an Agile system, whether developmental or operational, is created and operated with the intent of adaptation in an environment where continuous and unpredictable change can happen, typically with the explicit purpose of value creation, i.e. profitability, etc. (David F, Hasan H and Saya, 2009; Hallgren and Olhager, 2009a; Rigby, Sutherland and Takeuchi, 2016). Specifically, the ability to handle changing needs in a volatile market means being able to quickly introduce new products and handle variety (Gunasekaran *et al.*, 2019), and at the same time to coordinate, organize, and deploy resources as well as capabilities to serve market needs amidst varying conditions. It is quite evident from the literature that was published from the late 1990s onwards about agility, that there exists a range of similarities in the problems that organizations are facing today (Yusuf, Sarhadi and Gunasekaran, 1999; Dowlatshahi and Cao, 2006; Gunasekaran *et al.*, 2019). I.e., market segmentations and higher expectations from consumers, globalizations effects on the market changing the conditions for competitiveness, constant emergence of new technology that are centered on the shift towards a paradigm of Internet of Things (IoT) and industry 4.0, environmental footprints and socio-economic impacts, etc. (Sanchez and Nagi, 2001; Liyanage, 2012). Such industrial trends while triggering various forms of changes in the wider industry, have also affected agile thinking over the years.

Some scientific papers have been published considering the interactions between AM/EAM and agile. The seminal paper by Harris and Carapiet from 2006 is likely the first instance where the combination of the two subject matters is proposed (Harris and Carapiet, 2006). The considerations presented in the paper are centered on the argument that agile as a response to the rising complexity and turbulent operating environment, are here to stay. And, that the personnel responsible for AM efforts are embracing these changes, including uncertainty, permeable boundaries and exercising high levels of trust and communication to support cross organizational relationships and learning (Harris and Carapiet, 2006). Crombie in his paper from 2016, provides an exemplification of how Scrum a well-known agile method, can be adopted to introduce SMEs to the concept of AM (Crombie, 2016). An agile approach is proposed as a solution to the four barriers that SMEs are facing when approaching AM integration, *Cost, Time, Language* and *Value.* Thus, by structuring the implementation of the holistic AM integration in SME's, in smaller chunks that are integrated into a backlog of activities, the argument is that the process becomes achievable rather than daunting for the SME's (Crombie, 2016). Further, Ruitenburg, Braaksma and van Dongen in their 2016 paper, examines the interaction between agile as an important component of manufacturing and the interaction that exist with physical assets. I.e. the agility of the physical asset, which is likely designed for decades of operation in a stable context (Ruitenburg, Braaksma and van Dongen, 2016). Through three cases, the paper explores the drivers and enablers of agility and the interaction with Asset management application in the case companies (see table 1-1).

Table 1-1 - Agile drivers (Ruitenburg, Braaksma and van Dongen, 2016)

Agile drivers					
Technical	Economic	Compliance	Commercial	Organizational	Development

The paper concludes that agile in the context of AM is a determined by the need for agility in the assets, i.e. whether the agile drivers provide a need for change in the assets (Ruitenburg, Braaksma and van Dongen, 2016). Lastly, to emphasize the connection between agile principles and asset management, the latest iteration of the ISO 5500x series (2024) highlights adaptability as a key benefit of systematic asset management integration (ISO, 2024). This aligns with the advantages of an agile system setup, which is specifically designed to operate and adapt in environments characterized by continuous and unpredictable change.

1.1.3 Digitalization and EAM

Digitalization has been identified as one of the major trends in changing both society and business in the near- and long-term future (Parviainen *et al.*, 2017). The term digitalization was first introduced in 1971 in a paper by Robert Wachal, that discussed the social implications of the digitalization of society, considering the potential and increase in computer assisted research (Brennen and Kreiss, 2016). Brennen and Kreiss continues and defines digitalization as the "*adoption or increase in use of digital or computer technology by an organization, industry or country, etc."* (Brennen and Kreiss, 2016). Further, digitalization in the last decade has been contextualized through the lens of Industry 4.0. (Machado *et al.*, 2019), which was first detailed in a short article by Kagermann, Lukas and Wahlster (2011). The article introduced a new paradigm driven by digital technologies and intelligent systems, illustrating how these advancements would transform traditional manufacturing and production processes (Kagermann and Wahlster, 2022). The primary goal of Industry 4.0 is to increase efficiency, flexibility and customization in the manufacturing process, while reducing cost and environmental impact, mirroring the goals of AM (Masood and Sonntag, 2020). To achieve this goal of improved efficiency, etc., Industry 4.0 embraces the embedded and connected system and erases the boundaries between the physical and virtual factory. This is represented by a collective of technologies that enables the transition, i.e. Cyber-physical-systems and Internet of Things to exemplify (Machado *et al.*, 2019).

The interconnectedness between Industry 4.0. and digitalization is unquestionable, considering that digitalization aims to use technologies and data to improve and transform business processes, coincides with the goal of creating embedded and connected systems in Industry 4.0 context (Machado *et al.*, 2019). Further, considering that the vertical integration of systems at different hierarchical levels of the value creation chain and in the business process and the horizontal integration of several value networks across factories and the organization, as a key characteristic of Industry 4.0. (Algabroun *et al.*, 2022), the alignment with the definition of digitalization is viable and visible. This, further present a link to AM, as detailed in section 1.1.1. AM deals with the horizontal and vertical alignment and integration of the organization as well.

Asset Management is a data-intensive discipline that is dependent on recurrent asset information for decision-making that is viable for integration (Chang *et al.*, 2022). Further, a substantial portion of assets now exist as virtual entities, and their integration into digitally operated systems has become essential (Teoh, Gill and Parlikad, 2023). Assets must be digitally represented on operational platforms for various purposes, including capacity planning, service management, spare parts inventory, warranty tracking, and economic equity. Ahonen et al. (2019) highlight both the needs and enablers of digital asset management, while also identifying barriers such as insufficient technological readiness, lack of innovative business models, absence of appropriate tools, and high costs (Ahonen *et al.*, 2019).

The recent trend towards predictive maintenance and other predictive analytics applications underscores the necessity of digitalizing engineering assets to pursue these advancements (Cho, May and Kiritsis, 2020). With the decreasing cost and increasing availability of sensors, monitoring and tracking systems and products have become more feasible and efficient (Cho, May and Kiritsis, 2020). Consequently, the digitalization of assets within production systems is becoming more accessible, though companies must manage the complexity that such endeavors entail, as noted by Ahonen et al. (2019).
Applying digitalization measures within the scope of AM is a pertinent approach for companies seeking to enhance their insights into production, maintenance, and overall operations through increased data availability (Roberts *et al.*, 2018).

1.1.4 Research gap

This dissertation is built on several specific research gaps that have been identified in academic literature, and complementary views on the three different theoretical outlooks. To accentuate, the premise that asset management, agile and digitalization inherently are complementary figure 1 has been created and will be argued for in this section, along with argumentation for the different research gaps.

Firstly, the consideration of AM through the lens of agile is a relatively unexplored area of research. The literature regarding AM, and agile are each separately moderate to rich, however the exploration of the overlap between the two research areas less so. The available literature that explores this enhancement of AM through agile measures consists of a handful of papers (Baskarada, Gao and Koronios, 2006; Harris and Carapiet, 2006; Crombie, 2016; Ruitenburg, Braaksma and van Dongen, 2016). Nonetheless, considering the complementarity between asset management and agile approaches, it is feasible to augment existing asset management methods with concurrent agile practices. This Ph.D. project initially began in 2021 using the ISO 5500X series (2014/2018) as the guiding standards for asset management. However, these earlier documents did not recognize adaptability as a key benefit of an asset management system. In contrast, the latest iteration of the ISO 5500X standard (2024) explicitly identifies adaptability as a primary advantage of an integrated systematic asset management approach (ISO, 2024). This development aligns with the core benefit of agile systems - their inherent capacity to adapt and respond to evolving demands and requirements (Gunasekaran *et al.*, 2019). Thus, the 2024 standard reinforces the hypothesis formulated at the inception of this project: that agile methodologies and asset management are inherently compatible. Furthermore, the increasing complexity in managing assets - driven by factors such as rapid technological development, aging infrastructure, and workforce challenges (Herrmann and Bucksch, 2016)- underscores the need for adaptability in asset-intensive environments. As asset owners and managers are compelled to navigate continuous and unpredictable change, the integration of agile practices into asset management becomes not only feasible but necessary (Ruitenburg, Braaksma and van Dongen, 2016). This convergence of agile and asset management therefore represents a promising avenue for research, addressing the practical challenges faced by practitioners in dynamic and complex settings.

Secondly, the integration of digitalization and Industry 4.0 into Asset Management (AM) has been extensively explored in the literature, particularly in areas such as predictive maintenance, digital asset management, data-driven decision-making, and retrofitting existing equipment with digital capabilities (Aremu *et al.*, 2018; Macchi *et al.*, 2018; Alonso *et al.*, 2023). These advancements underscore the increasing convergence between digital and physical asset management practices. Given the complexity of modern AM systems, digitalization is not merely an enhancement, but a necessity, as effective systematization, categorization, and optimization of asset-related efforts are virtually impossible without digital support (Macchi *et al.*, 2018). However, existing research within the contemporary field of Asset and Maintenance management primarily falls into two distinct categories: studies that focus on technological applications (Predictive maintenance, digital twins, cyber-physical systems etc.) without fully considering their implications for business operations and those that examine business processes without sufficiently addressing their technological dependencies. While there are studies addressing aspects of digitalization within AM, particularly in the Danish industry (Grooss, Presser and Tambo, 2022), there is a noticeable gap in literature that systematically explores the intersection of digitalization, agile methodologies, and asset management from an industry maturity perspective. This gap is particularly evident when considering the implementation challenges and organizational readiness for digital transformation in AM (Stentoft, Rajkumar and Madsen, 2017; Brasen and Tambo, 2023; Maletič, Grabowska and Maletič, 2023). Moreover, research indicates a discrepancy between the theoretical discourse on Industry 4.0 and its practical integration within industries such as manufacturing, utilities, and maintenance (Sundberg, Gidlund and Olsson, 2019; Maletič, Grabowska and Maletič, 2023). While discussions on the digitalization of AM are well-developed in academic literature, real-world adoption often lags, suggesting the need for further investigation into the barriers, enablers, and organizational maturity levels that influence the successful implementation of digital and agile methodologies in AM (Stentoft *et al.*, 2021; Brasen and Tambo, 2023). Therefore, research that explores how digital interventions can align with industry maturity levels and drive agile adaptation in asset-heavy industries is both timely and essential for bridging this gap.

Finally, in the current industrial landscape, Asset Management (AM) is largely governed by the ISO 5500x series of standards, which include ISO 55000 (overview, principles, and terminologies), ISO 55001 (requirements for asset management), and ISO 55002 (asset management application guidelines). Together, these standards constitute the core framework for asset management practices, as detailed by Alsyouf et al. (2018), and have been the primary focus of this project. However, additional standards within the series, such as ISO 55010 (financial and non-financial alignment in asset management), ISO 55011 (development of public policy), ISO 55012 (people involvement and competence), and ISO 55013 (management of data assets), either published or revised in 2024, were not a significant part of this investigation.

While the ISO 5500x series is widely recognized for enabling value creation and preservation through its guidelines for asset management (Alsyouf *et al.*, 2018; Congalton and Gatland, 2019), there remains considerable ambiguity regarding its practical application. A multitude of the existing technical studies (Crespo Márquez *et al.*, 2020) have focused primarily on interpreting these standards within the context of asset maintenance management (Roda and Macchi, 2020). Despite the increasing complexity of asset management, there remains a gap in the literature regarding the integration of agile methodologies and digitalization within a broader asset management framework. This gap underscores the need for further research into the development of artifacts that explore the interaction between these three domains, offering significant potential for advancing both theory and practice in asset management.

Figure 1 illustrates the conceptual foundation of Agile Asset Management, emphasizing the interplay between Asset Management, Agile methodologies, and Digitalization as complementary and interdependent approaches. Traditional asset management, as structured by ISO 5500X series, focuses on value creation, risk and opportunity management, and lifecycle optimization (ISO, 2024). However, it is often constrained by rigid processes that limit adaptability in rapidly evolving operational environments (Maletič *et al.*, 2023). Agile methodologies counterbalance this rigidity by promoting adaptability, iterative development, and responsiveness to change, ensuring that asset management frameworks remain flexible and resilient (Hallgren and Olhager, 2009). Digitalization further enhances these approaches by enabling data-driven decision-making, process optimization, and real-time asset tracking, thus reinforcing efficiency, transparency, and strategic foresight (Danielsen, 2021). The integration of these three domains within a cohesive methodological framework - Agile Asset Management - addresses a gap in existing literature, particularly concerning industry maturity and implementation challenges. This framework offers a pathway to improved asset lifecycle management, optimized risk assessment, and enhanced value creation, making it particularly relevant in asset-intensive industries facing increasing complexity, technological disruptions, and evolving operational demands.

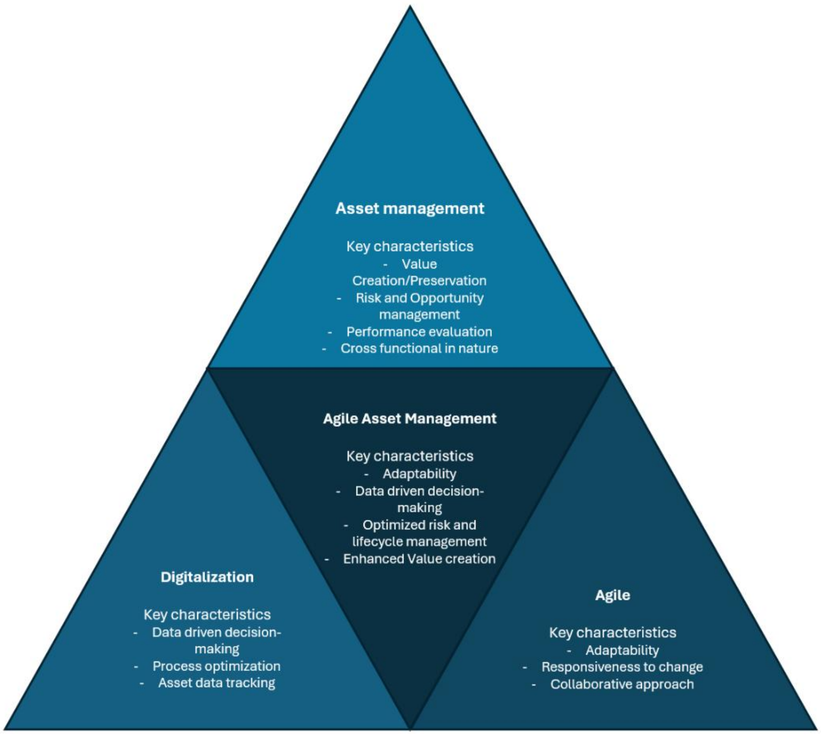

Figure 1-1 - Overview of Overlap of AM, Digitalization and Agile

1.1.5 Specific positioning

This dissertation adopts a synonymous approach to the use of "Engineering Asset Management" (EAM) and "Asset Management" (AM). While acknowledging that a distinction exists in the literature between these two concepts - each with distinct origin and meaning - the current industry standard, as reflected in ISO 5500x series, uses AM as the primary terminology. The ISO 5500x series, which has served as the benchmark for asset management since its publication in 2014, encompasses many of the principles originally associated with EAM, particularly in managing the operational aspects of assets. Although both AM and EAM are used interchangeably throughout this project and its associated publications, this was initially due to a lack of detailed understanding of their differences. However, this evolved into a deliberate choice, recognizing that EAM primarily targets the scientific community engaged in physical asset management research, while AM is more commonly employed by practicing professionals who align with industry standards. Consequently, the interchangeable use of these terms in this dissertation reflects a conscious decision to bridge the gap between academic research and industry practice.

1.2 Research Question

Based on the theoretical background and the identified research gap, the following question guides this dissertation:

How can Engineering Asset Management through integration with agile and digitalization, enable better navigation of an organizations strategic, operational and technological demands?

The overarching research question provides a framework for the dissertation and establishes the context for the work undertaken. The primary aim of this dissertation is not to answer this question directly but to utilize it as a guiding principle for the research efforts. Deriving from this overarching question, specific research questions have been formulated. These questions are empirically driven and have been developed incrementally, informed by the ongoing accumulation of research within the project. Consequently, these questions were not fully delineated at the project's inception but have evolved and matured as the research advanced.

To establish a robust academic foundation for this project, it was essential to explore both the existing body of knowledge and the practical realities of Asset Management, Agile, and Digitalization. This process involved developing a conceptual and practical framework that outlines their interaction and integration. By synthesizing insights from literature and industry practices, a structured foundation was created to assess the applicability of agile and digitalization within Asset Management. This, in turn, enables the formulation of specific recommendations for their integration, ultimately guiding applied interventions within organizational settings.

RQ1: What does a conceptual and practical framework for agile in the context of EAM/AM look like?

From answering RQ1, the following were clear. First, the context of agility as a management methodology is built upon specific tendencies that centers on processes of knowledge, work and control. Further, a strong complementarity was inferred between AM and agile, as both management methodologies are created with the intention of value creation and preservation. Agile from the perspective of the customer, visible through ongoing costumer interactions, continuous backlogs of activities related to demands and shorter iterative loops of work to ensure ongoing alignment and feedback (Kettunen, 2009; Gunasekaran *et al.*, 2019), to exemplify a handful of activities. Whereas the realization of value in AM is determined by the organizational objectives, the needs and expectations of the organization's stakeholders and the purpose and nature of the organization (ISO 55000 series, 2014). Thus, considering the interpretability of the industrial available guidelines for AM and the probable benefits for leveraging Agile as a management approach, RQ3 was partly formulated with these intentions.

RQ2: What does a conceptual and practical foundation for Digitalization in the context of EAM/AM look like?

Parallel with the answering of RQ1, answering RQ2 makes the following clear. First, that a strong interaction between asset maintenance strategies and the digital maturity exist. Digitalizing and enabling the application of data in the asset maintenance processes, reflected the operational and strategic context of the organization. Investments into technological improvements could provide benefits for the operational context and thus improve asset maintenance efforts. Crespo Márquez et al. (2020) book present a multitude of different papers correlating to specific uses of digitalization efforts for improved asset maintenance management and argues for the benefits of new trends in digitalization as the enabler for a new era of intelligent asset management systems. Yet, these trends and processes did not seem to line up with the technical capabilities in some the industry (Sundberg, Gidlund and Olsson, 2019). This lack of overarching digitalization maturity was likewise the generalized result in the Danish industry and suggested that a balanced approach to digitalization should be considered. I.e. considering the benefits and constraints of digitalization, would be the inclination that led to the formulation of RQ3 in conjunction with the agile outlook from RQ1.

RQ3: How can an applied EAM intervention that builds on agility and digitalization, enable AM compliance and the advancement of operational goals and objectives?

1.3 Methodology

The next section outlines the methodology used in this dissertation. First, the overall methodological considerations for the entire project will be presented to provide a clear framework. This will be followed by a brief introduction to relevant research methodologies. Then, a general research design will be discussed. Each chapter's specific methodology is detailed in the respective publications. The section concludes with an overview of the research conducted.

1.3.1 Overall methodological considerations

The overall methodological considerations are rooted in the introduced research gaps, which initially framed the methodology for the project.

First, the use of interdisciplinarity is needed, as the use of this requires specific positioning among research methodologies. In the context of asset management research, it was immediately clear that asset management encompassed a significant complexity that could not be attributed to a singular research discipline (El-Akruti and Dwight, 2010). Instead, this project aimed to examine and understand asset management through both a holistic and more directly applied perspective, considering the integration of agility and digitalization throughout. It was evident that a balance between engineering, business and social science research was necessary to grasp this understanding. From an engineering perspective, it was necessary to understand the applied asset management activities that dealt with the operational and maintenance efforts of the organization. Whereas the business and social science perspective was needed to grasp the organizational, strategic and human complexity that exists when introducing new managerial work methods that vertically and horizontally affect the organization.

Integrating closely with communities of practice has highlighted the necessity for pragmatic research approaches. Pragmatism, particularly in the American or Jamesian tradition, views beliefs as methods of action tailored to navigate uncertain environments (Bulleit, 2017). In this context, determining the truth of a belief equates to assessing its effectiveness in guiding us through such environments. This perspective aligns with the reality that engineers often make decisions before all scientific questions are resolved, leading to satisficing decisions that are "good enough" rather than optimal. Consequently, engineers rely on heuristics, practical, experience-based techniques, to guide their actions in specific situations (Bulleit, 2017). Further, communities of practice, specifically in the case of this PhD project, are the knowledge-specific communities where companies and asset management and maintenance management practitioners meet for networking and knowledge exchange activities (Wenger, 1998). These activities included but were not limited to company visits, webinars, networking meetings and seminars related to relevant subject matter. Thus, research methods that shortened the distance between the researcher and the cooperative instances where the research phenomena exist were necessary (El-Akruti and Dwight, 2010). In practice, this study involved an exploratory investigation into the differing interpretations of key concepts between practitioners and academic literature. Participatory research initiatives further generated new artifacts for the research subjects. Artifacts are defined as "artificial things that can be characterized in terms of functions, goals, and adaptation." In the context of design science research, such artifacts may include constructs, models, methods, theories, or instantiations (Dresch, Lacerda and Antunes Jr, 2015). In this project, the artifacts were specifically designed to address challenges identified in the asset management practices of the research subjects, incorporating agile methodologies and digitalization efforts. Thus, an immersive engagement with the research subjects was essential for understanding the practical criteria and parameters of asset management.

Third, concerning the research design, it had to accommodate a synthesis of theoretical outlooks, that contributes to the considerations of applying and integrating asset management with agility and digitalization's methods. Further, this theoretical synthesis should collectively emphasize the necessity of the research to contribute back to the research community and cover some of the identified gaps in research.

Lastly, it became apparent that the methodology employed needed to be adaptable throughout the project. From the onset, it was clear that close collaboration with asset management practitioners was essential, thereby necessitating an empirically driven approach. Consequently, the project had to remain responsive to the directions suggested by the data. This approach implied that insights gained from one phase should inform and potentially alter the scope and direction of subsequent phases. Therefore, to accommodate this need, a flexible and agile research design was imperative, allowing for the adaptation to incomplete knowledge and evolving assumptions.

1.3.2 Action research and Design science research

Concerning the nature of the presented research gaps and the methodological considerations, two methodologies are suggested for the project: Action research and Design Science Research.

1.3.2.1 Action research

Action research is "a transformative orientation to knowledge creation in that action researchers seek to take knowledge production beyond the gatekeeping to professional knowledge makers." (Bradbury-Huang, 2010). Indicating that it is method that through iterative inquires, design and develop solutions for real organizational problems, mainly through interactive participatory and observational methods (Saunders, Lewis and Thornhill, 2016). Following action research can often lead to change in or refinement of the initial scope of the research conducted as new insights are gained (Altrichter *et al.*, 2002).

The uniqueness of action research lies in the methods advocating of a flexible, pragmatic and collective response to problem solving (Altrichter *et al.*, 2002). Further, action research is one of a handful of terminological terms (*action learning, action science, action inquiry* and *action research*) that describes processes that through involvement with organizations, embraces the duality of conducting a practical transformation and of advancing knowledge (Huxham and Vangen, 2003). Thus, the first objective refers to the contribution of a research to a practical problem, and the second point coincides with the knowledge generated by the solution to the problem (Collatto *et al.*, 2018).

Action research is structured in a cyclical manner, Collatto et al. (2018) determines this as the following stages: *conducting a data analysis, plan actions, implement the actions and lastly perform* and *present an evaluation of the problem*, but variations to this proposed approach do exist (Huxham and Vangen, 2003; Azhar, Ahmad and Sein, 2010; Saunders, Lewis and Thornhill, 2016). Thus, in practice action research is constructed in an iterative manner, which means that each of the stages influence and build on the former, with the possibility of multiple iterative cycles to be had (Azhar, Ahmad and Sein, 2010). Thus, a responsive and dynamic approach is ensured that correspond to emerging problems and scope changes.

1.3.2.2 Design science research

Design Science Research (DSR), as a research paradigm has its roots in engineering and the science of the artificial, albeit heavily incorporated in information system and software engineering as well (Hevner *et al.*, 2004). However, the principles of DSR are applicable elsewhere (Collatto *et al.*, 2018), as, DSRs focus on the development and performance of artifacts is transferable to a wide range of other research disciplines, i.e. various management disciplines (Dresch, Lacerda and Antunes Jr, 2015; Collatto *et al.*, 2018). Artifacts and

solutions developed through DSR, can be constructs, models, methods, theory or instantiations (Hevner *et al.*, 2004; Dresch, Lacerda and Antunes Jr, 2015).
Artifact creation, solution prescription and performance enhancing are at the center of DSR, and these are created and enhanced through addressing real problems through close interaction between researchers and members of an organization (Dresch, Lacerda and Antunes Jr, 2015; Collatto *et al.*, 2018).

Different frameworks have been developed to accentuate the conduct of DSR in practice through the years, Collatto et al. proposes the following six elements for an adequate DSR design: *Problem, Solution, Development, Evaluation, Adding Value* and *Publicizing* (Collatto *et al.*, 2018). The first element refers to the formalizations of a relevant problem. The second element is the justification that the problem is necessary to solve, and that there exists no appropriate solution, thus, conducting the research is valid. Third and fourth element refer to the development and evaluation of a solution/artifact to the examined problem. The evaluation must consider the validity of the solution in a practical and academic sense, ensuring value for both, covering element five and six (Collatto *et al.*, 2018). However, it is imperative to detail that DSR inherently is not about creating a perfect solution to a problem, but rather to contribute a meaningful improvement to an existing solution (Dresch, Lacerda and Antunes Jr, 2015).
Another well-known framework for understanding and conducting DSR is Hevner et al. (2004) which proposes a framework for doing research in information systems. Hevner et al. framework emphasizes rigor and relevance as important in conducting DSR-based research. The framework is composed of three cycles, the relevance cycle (*relating and connecting the research to real-world problems*), the rigor cycle (*Connecting the research to existing scientific knowledge*) and the design cycle (*cyclical iteration between problem understanding, artifact creation and design, and evaluation*) (Hevner *et al.*, 2004; Hevner, 2007).

1.3.2.3 Research design

In accordance with the presented methodologies and guidelines, a comprehensive research design was developed. The project primarily adheres to the Design Science Research (DSR) methodology, with action research (AR) is incorporated in the research design as well. While Baskerville (2008) rightfully argues that DSR and AR are distinct methodological approaches, their complementary nature is particularly relevant in the context of this dissertation. DSR is concerned with problem-solving through the creation and contextualization of artifacts within a natural setting, whereas AR is oriented toward problem-solving through iterative interventions that drive societal and organizational change (Baskerville, 2008). The integration of both approaches is necessary, given that asset management operates across organizational boundaries and disciplines, requiring a methodological framework that accommodates both the development of tangible solutions and the management of systemic change. Järvinen (2007) provides further evidence for the synergy between these approaches, demonstrating that DSR and AR share key characteristics, particularly in their cyclical, iterative nature and their focus on improving practice through direct intervention. While DSR is instrumental in the design and implementation of artifacts, such as the model developed in paper 5, AR enables the evaluation and refinement of these artifacts within real-world organizational contexts. This interplay ensures that the designed solutions are both theoretically rigorous and practically viable.

In the context of this dissertation, the two approaches serve distinct yet interconnected functions. DSR provides a structured means of developing artifacts that support industrial agility in asset management, ensuring that solutions are systematically designed and assessed. However, given that asset management processes do not operate in isolation but are embedded within dynamic socio-technical environments, AR is crucial for understanding and facilitating the organizational adaptation required for the successful adoption and integration of these artifacts. The combination of DSR and AR thus enables a holistic approach, wherein designed solutions are not only sound but also aligned with the evolving needs and constraints of the industrial ecosystem. By employing both DSR and AR, this research ensures that the theoretical contributions made through artifact development are validated and refined through practical implementation and iterative learning.

The selection of DSR as the overarching methodology was based on the consideration that the project should have practical relevance for practitioners in asset and maintenance management. It was deemed essential to provide tangible insights applicable to communities of practice and companies engaged in or interested in AM. Additionally, it was necessary to contribute theoretical knowledge to academic discourse. Based on these considerations, a visualization of the research design was created (see Figure 1-1).

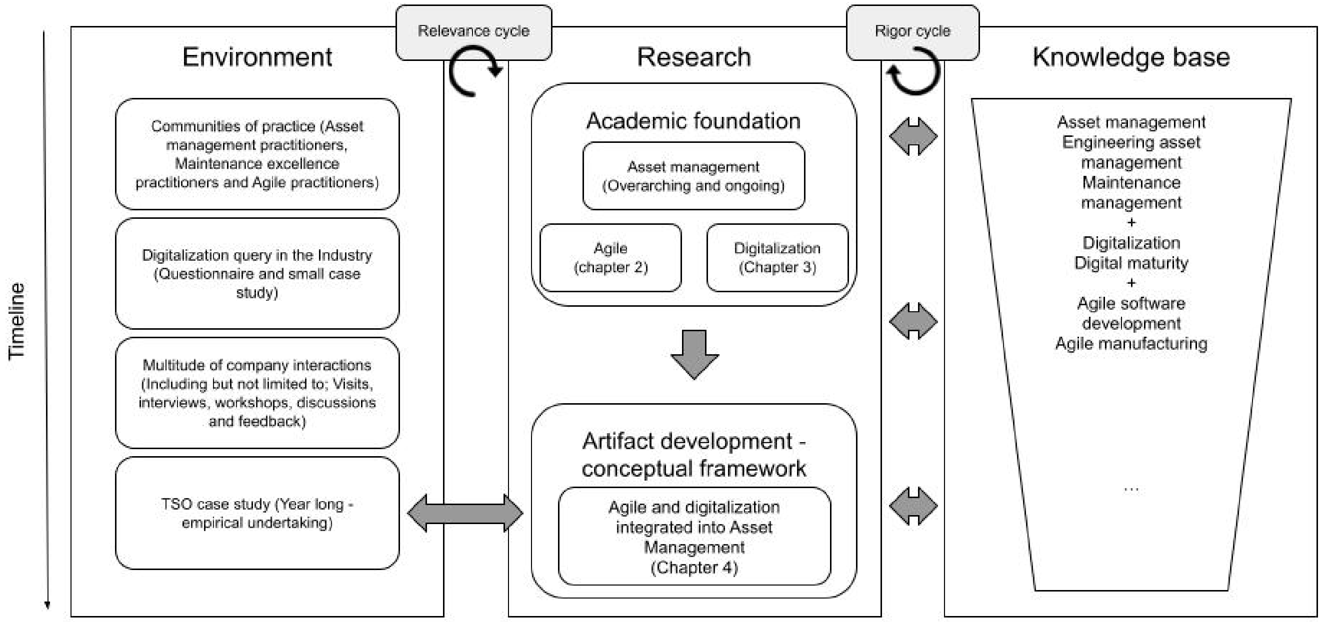

Figure 1-2 - Visualization of the research design model, built on DSR and Action Research

The research conducted in the project, is divided into three distinct parts on account of the sub-RQs, with an overarching throughline centered on the main RQ, all contributing to the overall outcome of the project. The focus of the throughline was a constant process throughout the project, that contributed to a significant portion of the empirical insights gathered on the practical realities of asset management professionals. These empirical insights were gained through the involvement and collaboration with communities of practice on agility, asset management and maintenance excellence, which provided a foundational understanding of the practitioner-based view on the subject matters. From the onset of the project in February 2021, it was clear that there existed a distinct gap in the practical versus literary understanding of especially asset management. Which was immensely interesting and ensured that balancing the realities of practical applicability and theoretical relevance would be an ongoing effort.

The first specific part involved an exploratory investigation of existing literature on agility, utilizing established academic sources. The narrative literature review were constructed based on these systematic steps and the following keywords ("Asset management", "Agile Manufacturing", "Engineering Assets" and "Industrial Ecosystems") using academic databases (SCOPUS, ScienceDirect and Google Scholar), citation tracking, and iterative refinement based on relevance and rigour. To exemplify, one of the used search strings would be structured as follows: ("Asset management" OR "Engineering Assets") AND ("Agile Manufacturing"). This phase provided a robust academic foundation about agility, elaborating on key processes inherent to agile methodology, and synthesizing the relationship between AM and agility. Furthermore, the insights obtained were fed back into the knowledge base, enriching the theoretical framework.

The second part mirrored the first, involving an exploration of existing literature on digitalization, particularly from the perspective of maintenance and data, and the interaction between digitalization and

Asset Management. The review process followed systematic steps to construct the narrative literature reviews, including keyword-based searches using terms such as (“Asset Management”, “Digitalization”, “Predictive Maintenance”, and “Industrial Data”) in academic databases (SCOPUS, ScienceDirect, and Google Scholar), as well as citation tracking and iterative refinement based on relevance and rigor. For example, a representative search string was: ("Asset Management" OR "Engineering Assets") AND ("Digitalization" OR "Industrial Data"). Additionally, it examined the practical realities of digitalization maturity through a quantitative dataset collected from practicing professionals.

The final stage of the research involved an immersive case study, constituting a substantial portion of the project’s empirical work. This case study adopted a dual-methodological approach, integrating AR and DSR to address a practical problem within the case company (Collatto *et al.*, 2018). While AR was employed to understand and intervene in the company’s asset management activities, facilitating iterative improvements, DSR provided the structured framework for designing and positioning an artifact that encapsulated the integration of agile methodologies and digitalization. Conducted over a year-long period, the case study began with an exploratory analysis of business processes to identify key challenges and areas for improvement. This led to the identification of a specific organizational domain where intervention was most needed. An improvement initiative was subsequently developed, culminating in the design of an artifact aimed at enhancing decision-making through risk within asset centric activities. The role of DSR in this process was pivotal, as it ensured that the artifact was systematically developed, positioned within the organizational setting, and aligned with the necessary theoretical principles.

However, the focus was not solely on the creation and implementation of the artifact. Instead, the research aimed to generate empirical insights into the interplay between asset management, agility, and digital transformation (Dresch, Lacerda and Antunes Jr, 2015). AR facilitated this learning process by enabling continuous reflection, adaptation, and refinement of both the artifact and the surrounding management practices. Furthermore, the iterative cycles of data collection, evaluation, and modification carried out throughout the case study reinforced the principles of AR (Collatto *et al.*, 2018). This cyclical engagement allowed for an ongoing dialogue between theoretical constructs and practical applications, ensuring that the proposed solution was not only viable within the case company but also contributed to broader knowledge on agile asset management. By integrating AR and DSR, the research methodology enabled both the design of a tangible solution and the generation of actionable insights, demonstrating the value of a mixed-methods approach in addressing complex organizational challenges.

1.3.2.4 Research Approach

The following present the applied research approaches used in the project, from the sampling of the case studies (Sub-chapter 3.1 and Chapter 4) to the consideration regarding the data collection.

Assessment of publicly available data on companies certified in asset management revealed that four Danish companies are included, all of which operate in the utilities sector. A common characteristic among these companies is that they each manage very large and expensive asset portfolios (ISO, 2025). Accordingly, the initial overview of companies to investigate seemed limited, meaning that other opportunities for gaining initial access to discourse on the practical realities of asset management were examined. This led to the involvement with the communities of practice, specifically networks facilitated by the Danish Maintenance Association on Asset Management for practitioners and the Maintenance excellence network and Asset Management Denmark’s working group on Organization and Management. Engaging with these communities of practice did not directly yield data for scientific publications. Instead, it provided detailed insights into the real-world experiences of asset management and maintenance management practitioners and served as an ongoing source of feedback and information. Additionally, this engagement supported the study’s sampling methodology, which primarily relied on convenience and snowball sampling techniques. The feasibility of the research depended on the willingness of companies to grant access to their organization and confidential data. Many companies are understandably hesitant to allow an external researcher, who is essentially a stranger, to access their comprehensive data.

Consequently, the pool of potential case studies was inherently limited to organizations demonstrating a certain level of trust and openness. This limitation influenced the selection of cases significantly and resulted in the singular case study conducted for the year-long study (Chapter 4). While a single case study might appear limited in terms of statistical generalization, it remains fully aligned with the study's purpose. Flyvbjerg (2006) argues that the value of case studies does not rest on their ability to produce broad generalizations but rather on their ability to provide deep insights into complex phenomena. He refutes the claim that one cannot generalize from a single case, emphasizing that well-chosen cases, whether extreme, critical, or paradigmatic, can be instrumental in falsifying assumptions and refining theoretical understanding. Moreover, the paper stresses that the number of cases is less important than their strategic selection, as a single case can often reveal insights with implications beyond its immediate context (Flyvbjerg, 2006).

In addition, Halkier (2011) discussion of methodological practicalities in analytical generalization highlights the importance of systematically linking case findings to established theoretical frameworks. By articulating the underlying theoretical constructs and the contextual conditions of the study, researchers can extend the implications of a single case to broader theoretical discussions (Halkier, 2011). In this project, such an approach is employed to examine the rethinking of AM within agile and digitalization context, ensuring that the study's in-depth analysis not only captures local realities but also contributes meaningfully to wider conceptual debates.

Throughout this project multiple sources have provided data, of both primary and secondary nature. The primary data originates from the interactions with companies, communities of practice, relevant conferences and asset management practitioners. For the case study, the data has been collected through several different methods. With the year-long interaction with the case company, conducted through an immersive participatory approach, the data collected centered on the interactions with the organization, their asset management system and the personnel performing the work. Primary data was gathered by conducting interviews, engaging in developmental workshops and general interactions in the environment of the company. Secondary data is represented by business data on strategic asset management plans, asset management plans, process documentation and generally available documentation in the information systems present in the case company. Table 1-2 offers a comprehensive overview of the data collected for this dissertation.

Table 1-2 - Overview of data gathered for the dissertation

PAPER AND DISSERTATION SPECIFIC	DATA COLLECTED
THE ROLE OF KNOWLEDGE, CONTROL, AND WORK PROCESSES WITHIN AGILITY	Narrative literature study – • Academic material (Journal and conference articles, teaching cases, reports, presentations)
ON DEFINING INDUSTRIAL AGILITY AS A STRATEGIC CAPABILITY FOR COMPETITIVE PERFORMANCE OF ENGINEERING ASSETS: AN INDUSTRIAL ECO-SYSTEMS PERSPECTIVE	Narrative literature study – • Academic material (Journal and conference articles, teaching cases, reports, presentations) • Industrial Standards (ISO) • Media articles (Newspapers, articles, press releases) Model Development – • Workshops • Brainstorming sessions focused on co-creating a suitable model
COMPARISON BETWEEN DATA MATURITY AND MAINTENANCE STRATEGY: A CASE STUDY	Narrative literature study – • Academic material (Journal and conference articles, teaching cases, reports, presentations) • Industrial Standards (ISO) • Media articles (Newspapers, articles, press releases) Case study – • 4 company interviews (Danish Production)

	• Interviews 30-45 minutes (On-site or over phone) • Observations (In production environments)
THE EXPLORATION OF DIGITALIZATION AND DIGITALIZATION INDICATORS WITHIN THE SCOPE OF ASSET MANAGEMENT	Narrative literature study – • Academic material (Journal and conference articles, teaching cases, reports, presentations) • Industrial Standards (ISO) • Media articles (Newspapers, articles, press releases) Maturity assessment – • Quantitative survey (128 questions – 66 respondents)
AGILITY AND ASSET MANAGEMENT: EFFICIENCY IN DECISION-MAKING FOR OPERATIONAL LIFE-CYCLE PROJECTS IN TRANSMISSION SYSTEM OPERATORS	Narrative literature study – • Academic material (Journal and conference articles, teaching cases, reports, presentations) • Industrial Standards (ISO) • Media articles (Newspapers, articles, press releases) Case study – • Longitudinal singular case study (TSO) o Interviews and workshops ▪ *Director of Asset Interview #1* ▪ *Workshop #1* ▪ *Workshop #2* ▪ *Workshop #3* ▪ *Director of Asset Interview #2* ▪ *Workshop #4* o Documentation ▪ Internal Asset Management System ▪ ERP system ▪ Documentation and Case-handling software
GENERAL ACTIVITIES FOR PHD PROJECT	• Communities of practice integration (Asset Management For Practitioners (DDV), Maintenance Excellence (DDV) and Organization and Management (Asset Management Denmark)) • Company collaborations • Expert interactions

The case study's development of an artifact did not only create engagement with the relevant personnel in the company but provided necessary and relevant data. Through direct interaction with the case company's system and documentation, in addition to the interaction with people in the organization, the creation of the artifact deliberately provided hands-on experience with the operational aspect of the organization. Thus, providing the opportunity of collecting primary data, which distinctly provided valuable insights into the foundational elements of AM compliance and daily operations. The workshops that were held to establish wanted features in the developed artifact, in correlation with the specific problem that should be solved through the artifact creation, provided research findings integral to the key topics of the project.

Beyond the primary and secondary data gathered as part of the year-long case study, other secondary data have been used. This was primarily represented through business data and established literature. The business data was a blend of information gathered on companies beyond the final case study done. This included multiple company visits, and the interactions with practitioners in the communities of practice. These interactions provided presentation materials, overview of asset management certification efforts in the form of documentation and variety of different business process documents and data. The data while not providing a specific scientific publication was necessary for the ongoing development of understanding the practical realities of AM.

The last part of the secondary data came from existing literature. Throughout this project literature has been constantly investigated and revisited to develop and understand the working of the theoretical fields investigated in the project. This was necessary and relevant to undertake, as the ongoing progression of the research in the project, but just as importantly in the knowledge environment developed. While there for the extension of the project have been an aim to investigate and only sources from acknowledged and peer-reviewed journals and proceedings, the reality is that a significant portion of the research conducted on AM and EAM is presented in conference proceedings and books. One example that is of relevance is the World Congress on Engineering Asset Management (WCEAM). WCEAM as a conference community is critical for the development of EAM, as the conferences history and ongoing presence as a community for practitioners and academics to share relevant research and EAM projects. Thus, an active choice was made to include conference proceedings and other relevant material, to include the newest research and the literature from the important conference communities.

1.3.3 Research Overview

The dissertation is composed of a series of published and submitted papers and which makes up the following chapters. All papers are published or submitted to acknowledged peer-reviewed conferences or journals. The conferences or journals have been selected based on the relevance to the topic of the individual papers. An overview of the included papers is presented in Table 1-3.

Table 1-3 - Papers directly included in the Dissertation

CHAPTER	TITLE	CONFERENCE / JOURNAL	REFERENCE
CHAPTER 2	The role of knowledge, control, and work processes within agility	European Conference on Management, Leadership & Governance (aci)	(Brasen et al., 2021)
CHAPTER 2	On Defining Industrial Agility as a Strategic Capability for Competitive Performance of Engineering Assets: An Industrial Eco-systems Perspective	International Conference on Industrial Engineering and Engineering Management (IEEE)	(Brasen, et al., 2022)
CHAPTER 3	Comparison between data maturity and maintenance strategy: A case study	54th CIRP Conference on Manufacturing Systems (Elsevier)	(Brasen et al., 2021)
CHAPTER 3	The Exploration of Digitalization and Digitalization Indicators Within the Scope of Asset Management	Lecture Notes in Mechanical Engineering (Springer)	(Brasen et al., 2023)
CHAPTER 4	Agility and Asset Management: Efficiency in Decision-Making for Operational Life-Cycle Projects in Transmission System Operators	Energy Research & Social Science (Elsevier)	Submitted -under review

Furthermore, a substantial amount of work has been completed to support the chapters in the form of working papers that have not been developed to a submittable state yet. These papers are not included in the dissertation but are supportive work that can be used to gain a better understanding of the included work. The working papers are present in the appendix and an overview of these papers can be found in Table 1-4.

Table 1-4 - Working papers still under development

TITLE	CONFERENCE / WP	REFERENCE
INDUSTRIAL AGILITY AND ENGINEERING ASSET MANAGEMENT - TOWARDS AN AGILE ASSET MANAGEMENT FRAMEWORK	Working paper	Not submitted

KNOWING WHAT WE HAVE AND WHERE TO GO – REVIEWING ASSET MANAGEMENT POSITIONS IN PROFESSIONAL COMMUNITIES OF PRACTICE IN DANISH INDUSTRY	Working paper	Not submitted

2 Chapter 2. – Agile and EAM

The following chapter consist of two publications that each outline different aspects of agile, aiming to answer RQ1. *The role of knowledge, control, and work processes within agility* details three fundamental process to agile within the context of leadership, governance and management. This paper largely builds upon the influences of agile software development, but correlates that with an investigation of the past to determine trends within conventional agile methodologies from past applications. As stated in the conclusion of the paper, agility can be a large and comprehensive beast to tackle, thus, the paper set out to examine that beast, and detail the fundamentals of agility for ease of understanding and application. Finally, a significant development from the inception and writing of this paper in 2021, to the end the PhD project in 2024 happened. Specifically, the singular focus on agile software development as the conceptual framework, exemplified through the agile process paper, needed to shift to accommodate for the ongoing development of the authors understanding on the subject. But just as necessary the continued development of the industrial perception on agility as the end all be all for management methodology, changed during the project period (Skovgaard, 2024). The argument for a more balanced approach towards agile became prevalent (Lynge, 2024). Thus, the second paper outline a conceptual framework set out to abide that.

On Defining Industrial Agility as a Strategic Capability for Competitive Performance of Engineering Assets: An Industrial Eco-systems Perspective, in line with the previous paper on agility examines the structures of agility, through the lens of agile manufacturing especially. The paper in contrast to its predecessor, focusses significantly more on Asset management, and contextualizes agility in relation to engineering asset, and the industrial system within which agility should be applied. This led to a proposed definition for the concept of industrial agility and an artifact correlating this concept of industrial agility, the industrial eco-system and engineering assets. The paper arguing that Industrial agility enables the pursuit of opportunities and management of risks duly, with the goal of this, enabling business value creation.

The content of the chapter is directly copied from the papers, with some corrections and additional content added to enhance the papers.

2.1 The role of knowledge, control, and work processes within agility

The following conference article partly answers RQ1.

Brasen, L. P. H. & Tambo, T., 8 nov. 2021, Proceedings of the 17th European Conference on Management, Leadership and Governance, ECMLG 2021. Academic Conferences and Publishing International Limited, s. 83-89 7 s. (European Conference on Management, Leadership & Governance). DOI: 10.34190/MLG.21.083

The published version of this paper can be found here:
https://www.proquest.com/docview/2616894200?pq-origsite=gscholar&fromopenview=true&sourcetype=Conference%20Papers%20&%20Proceedings

The content of this subchapter is directly copied from the paper, with some editing and additions added to the text, to create a better flow and enhance the methodological considerations in the paper.

Abstract: Agility has through the last two decades become a significant part of organizational strategy, to ensure higher effectiveness, learning capabilities, and competitiveness in an increasingly complex and competitive business environment. However, even though agile as a term has existed for only 20 years and started specifically as a method of working with software development, agility and methods derived from agility have spread to almost every part of the organization. From production optimization to project management and large-scale organizational frameworks. The use of agile methods has generally provided improvements for the organizations that choose to adopt them, but a steep learning curve contributes to a need for skilled people. This paper seeks to establish key theoretical fundamentals on agility related to management, leadership, and governance, by reviewing literature on agility. The key findings in the paper suggest that the essential processes of; control, work, and knowledge are significant contributors to ensuring success with agility. The paper will highlight these processes and elaborate on the three processes' relevance for organizational agile success, through the means of management, leadership, and governance. The categorization of the three processes is conducted through a theoretical taxonomic understanding of agility in organizations and literature. The practical implications of the paper are a specific outline of control, knowledge, and work processes within agile methods, specifically as the field of agile both in research and application have become muddled with frameworks and methods build upon the Agile Manifestos. The research implications of the paper are the showcasing of processes within agility that has potential for exploitation both in an organizational perspective, but also to support the authors' further research into deriving agility from a development specific focus to an operational aspect of the organization, with a production centered approach. This also correlates with the originality of the paper, which relates to theorizing on the implications of agility from development processes to the production-centered operations of the organization.

Keywords: *Agility, Control processes, Knowledge processes, Work processes, and Iterative methods*

2.1.1 Introduction

The term Agile was coined three decades ago as a manufacturing methodology but was quickly adapted and introduced as a methodology for software development, project management, and organizational strategy. Software Agility started as the brainchild of 17 industry leaders within software development, which, through their irritation with the lack of suitable methods for software development projects set out to outline a manifesto, that incorporated their vision and thoughts on the future of agile software development (Beck *et al.*, 2001). Four core values are presented in the manifesto that should be focused on (Beck *et al.*, 2001; Serrador and Pinto, 2015):

- Individuals and interactions over processes and tools
- Working software over comprehensive documentation
- Customer collaboration over contract negotiation
- Responding to change over following a plan

The emergence of the agile manifestos led to a paradigm change in organizations around the world from more traditional development methodologies to embracing agility and changing their organizational strategy to an agility-based one (Zielske and Held, 2021). This has led to an industry of consultants, process developers, and industry influencers working with the principles of the agile manifestos and interpreting these, putting the values into systems, and developing an original take on these principles coined for software development (Serrador and Pinto, 2015). Thus, Agile went from principles in a manifesto targeted towards software developers to a wide-reaching movement spreading Agile to product developers and managers leading whole organization (Jindal *et al.*, 2021). Thus, considering this widespread application and popularity of Agile, the methodology has become wide-reaching, albeit with significant shifts in the underlying guiding principles and added application thereof (Hummel, Rosenkranz and Holten, 2013). Considering, the proliferation of Agile methodologies and frameworks derived from the core values and principles outlined in the Agile Manifesto, it is evident that Agile has evolved far beyond its original scope in software development. This evolution has expanded Agile into broader organizational strategies, product development processes, and leadership paradigms. While this expansion has led to widespread adoption and the development of diverse models - such as Scrum, SAFe 5.0, and eXtreme Programming (Hummel, Rosenkranz and Holten, 2013) - there is a need to critically examine the theoretical foundations of agility as they pertain to management, leadership, and governance.

This study aims to address this gap by establishing the key theoretical fundamentals of agility that are relevant to these domains. By conducting a narrative literature review, it seeks to answer the following research question: *What are the key theoretical fundamentals within agility that relate to management, leadership, and governance?* Furthermore, the paper outlines practical processes within Agile that can be applied in organizations to bridge the gap between theoretical principles and actionable strategies.

By exploring these theoretical fundamentals and their practical applications, this study contributes to a deeper understanding of how Agile principles can inform and transform organizational practices, particularly in leadership and governance. It also examines how the foundational values of the Agile Manifesto have been adapted, expanded, and reinterpreted in various organizational contexts, shedding light on the coherence, or lack thereof, between Agile's core values and its modern implementations.

2.1.2 Theoretical background

The theoretical foundation of this study is grounded in the historical evolution of Agile and iterative methodologies, with particular emphasis on their rapid advancement over the past three decades. This foundation is developed through a narrative literature review, following the framework proposed by Baumeister and Leary (1997), specifically their third and fifth types of narrative review. The inspiration of the narrative literature review frameworks is especially relevant as the agile methodologies as a field have evolved significantly since their inception, thus aligning well with the narrative literature reviews more in-depth explorative approach, accommodating the wide-ranging nature of the topic. The study aims to explore the role of knowledge within Agile methodologies, tracing their historical trajectory from the early iterative methods of the early 20th century to contemporary Agile development approaches. This examination is situated within the broader contexts of management, governance, and leadership, providing a comprehensive lens through which to understand the interplay between knowledge and Agile practices, thus arguing for the theoretical fundamental processes detailing and guiding Agile methods.

2.1.2.1 The brief history of Agile and iterative methods

Even though agile as a term has been around for only a short period of three decades, the thoughts and values presented in the agile manifestos were not new. One example is the fourth value, responding to change rather than following a plan, which had its foundation in the early production optimization era. Iteration, as is the direct product of this value, has been around since the Plan-Do-Study-Act (PDSA)-cycle was introduced by Walter Shewhart to his mentee W. Edwards Deming as a means of improving products and processes (Rigby, Sutherland and Takeuchi, 2016). The PDSA-cycle was then used extensively in Japanese companies by Deming following the Second World War. Especially, Toyota used Deming to train hundreds of managers, eventually building upon his success and creating the Toyota Production System (TPS). TPS is the primary source of current Lean thinking.

In 1986, Hirotaka Takeuchi and Ikujiro Nonaka published a paper in Harvard Business Review by the name of “The New New Product Development Game.” This article studied manufacturers that released successful innovations far faster than competitors could (Takeuchi and Nonaka, 1986). The article identified that a team-focused approach that changed the design process and development process for products such as cameras and printers. Rather than following a standardized waterfall approach, where one group of specialists hand off the project to the next (Takeuchi and Nonaka, 1986). These companies were using what Takeuchi and Nonaka coined the “rugby” approach, where the ball or product is passed back and forth by the whole team for the complete duration of the project.

In 1995 Jeff Sutherland and Ken Schwaber presented Scrum for the first time, a name that is a direct reference to the article by Takeuchi and Nonaka, which were a large inspiration to the method. Sutherland had a seemingly impossible project to complete if conducted through “traditional project methods.” However, Scrum enabled him to complete the project on time, under budget, and with fewer revisions(Rigby, Sutherland and Takeuchi, 2016). To briefly exemplify Scrum, it is an iterative and incremental development methodology, that uses holistic and flexible tools and roles to ensure that the development team is one entity trying to reach the same goal and targets (Naz, Khan and Aamir, 2016). These tools can take different shapes but can range from daily face-to-face meetings to align expectations to allowing ongoing requirement changes from the customer, which is possible as the setup is incremental and iterative, with an iterative loop being roughly two to four weeks, allowing for this rapid adaptation. Furhter, different necessary roles exist within Scrum i.e. Product owner (The product owner is the representative of the customers and stakeholders, thus determining the requirements for development through the medium of user stories.), Development team (three to nine members typically, that are liable for delivering a complete and deliverable product at the completion of every sprint.) and lastly Scrum Master (Responsible for removing problems and obstructions so that the development team can deliver a quality project and ensures that Scrum rules are followed.) (Naz, Khan and Aamir, 2016). Scrum is, however, not the only iterative method that emerged in the ’90s, the advent of the Information Age and the disruptive technologies that followed set the companies that could not adapt to the changes quick enough on the back foot (Serrador and Pinto, 2015). Hence, a significant number of start-ups and industry leaders sought to adapt to the changes that were inbound and ongoing. Software became an integral part of the business process and software developers all around the world worked on creating better methods for software development (Cram and Marabelli, 2018).

This led to the 17 industry leaders meeting in 2001 and the term agile was established. Agile was born both as a term for gathering the movement under a collective terminology, but also to combat the less than flattering term used for methods such as Scrum at the time; Light weight. The term stemming from the simpler rules and faster adaptation(Beck *et al.*, 2001; Rigby, Sutherland and Takeuchi, 2016).

The significance of PDSA and TPS for agility is that iterative thinking has become a stable of the agile way. Certain agility-centered frameworks e.g. Scrum are built upon the use of loops to ensure that the changing requirements from the customer are continuously dealt with through thorough reviews and evaluations(Schmidt and Sun, 2018).

Furthermore, Lean thinking which was derived primarily from TPS is highly associated with agility. Some agile purists would argue that the two methodological approaches are separate entities entirely, most are at this point convinced that they originate from somewhat of the same source and the focus on customer collaboration is intrinsic to agile values and principles (Rigby, Sutherland and Takeuchi, 2016; Hemalatha, Sankaranarayanasamy and Durairaaj, 2021).

The covering of the history of agility is significant for the mapping of the theoretical fundamentals of agility. Agile had a large and complex past beyond the foundation of the terminology in 2001, and this understanding of the experiences and methods that inspired and influenced the agile movement is necessary to look toward the future and ensure that the theoretical fundamentals are in line with what was intended in the past. Especially in the current business environment where agile has spread throughout organizations from a software-centered approach, going full circle with the methods of the past, embracing iterative processes that, in large part, signify agile.

2.1.2.2 Fundamentals of Agile

Agile can no longer only encompass the 4 values and the 12 principles of the agile manifestos. Agile is an ever-evolving methodology that is interpreted in large part in the eyes of the practitioner (Lill and Wald, 2021). In general, the agile manifestos provide what is known as the agile mindset, however, the application of this mindset varies greatly between practitioners which has led to discourse and a variety of understanding of the application of agile (Llamas *et al.*, 2016). This section will try to peer through some of that discourse and map the theoretical fundamentals of agility from a management, leadership, and governance perspective.

Thus, investigating the varied applications of agile and the multitude of frameworks that have been prevalent for the last 3 decades is significant. Scrum is a prime example of a stable agile-centered methodology that has been used for both software development and later throughout organizations as a whole (Llamas *et al.*, 2016). Scrum is typically applied on a small scale, with the practice working best in small development operations of 3-9 people. However, it can be implemented in large-scale agile-based frameworks, such as SAFe. 5.0 or Large-Scale Scrum (LeSS), both of which are implemented throughout the organization rather than in specific departments or development teams specifically (Zielske and Held, 2021). The frameworks targeted toward the larger organization are typically comprised of small-scale development teams within a larger-scale development organization or department. With managers and processes running parallel to what is seen in Scrum, for example, but with longer timeframes and more participating individuals (Zielske and Held, 2021).

The reason for highlighting Scrum specifically is that is one of the most well-known practices working with agile and the application of the agile values into the practice by the iterative nature the practice embraces in the planned development process is well proportioned (Napoleão et al., 2021). It also deals with management and leadership in an interesting way that ensures that the customers' requirements are coherently formulated to the development team, through the medium of user stories based on the customer requirements (Zaina, Sharp and Barroca, 2021). Furthermore, a key feature in Scrum is that no one is above the process, meaning that even though a manager would try to influence the work done in the team, it has to be done within the restraints set by the Scrum process (Schmidt and Sun, 2018).

Scrum and other agility-centered frameworks work based on the values from the agile manifestos. But underneath that certain processes that guide the management, leadership, and governance of the agile application can be found. Three processes stand out, control, work, and knowledge processes. These processes, going beyond the scope of the agile manifestos, focus on software development and fundamentally provide insights into the managerial aspects that allow for success with agility. The process of control is centered on controlling the flow of agility, specifically tracking the work conducted, with specific tools rather than extensive documentation. Examples are boards for tracking progress, ensuring administrative control of time and budget, and evaluative meetings at the end of iterations for reflection and review of the project (Lill and Wald, 2021).

The process of work focuses on the structure and practices applied to maintain it throughout agile projects or applications. This is exemplified largely through iterative periods that allow for the reflections and reviews to align with customer requirements. Stand-up meetings are another example of a work practice that is applied widely both through agile-centric teams, but also in an operational context to evaluate the last days' work and assign new tasks if necessary (Tessem, 2014; Zaina, Sharp and Barroca, 2021).

The last process of knowledge relates to the application and retention of knowledge within the organization or team applying agility. Certain practices allow for knowledge to be applied in the right circumstances, the iterative way of working is key to that. Iteration allows for reflection, review, and adaptation to the circumstances that emerge (Napoleão *et al.*, 2021). This is applicable in a development project as well as in daily operations.

The identification of control, work, and knowledge processes as the theoretical fundamentals of agility stems from a synthesis of Agile's historical evolution and its application in contemporary frameworks. The iterative thinking embedded in Agile, rooted in early methodologies like Shewhart's PDSA cycle and Toyota's Lean principles, highlights the centrality of structured *control* mechanisms for tracking progress, managing resources, and ensuring adaptability (Naz, Khan and Aamir, 2016). Similarly, the collaborative and iterative approaches pioneered in frameworks such as Scrum emphasize *work* processes that maintain alignment through reflection cycles, stand-up meetings, and incremental development loops . Finally, Agile's intrinsic focus on adaptability and continuous learning underscores the importance of *knowledge* processes, enabling teams to capture and apply insights effectively to meet evolving customer needs (Napoleão *et al.*, 2021). By integrating these processes, Agile operationalizes its values and principles, bridging the theoretical foundations of its history with practical applications in management, leadership, and governance today. This alignment reflects Agile's evolution from its roots in iterative manufacturing practices to its current widespread adoption across industries.

2.1.3 Perspectives of agility in practice

Within the field of management, leadership, and governance an understanding of the intrinsic values and principles that make up most of the agility-centered frameworks is needed. Both to ensure that the application of the agile values is represented when trying to implement agility in an organization, but also to allow the individuals performing the value-generating work for the customer to embrace agility. To accommodate that, this section will delve deeper into the three processes to ascertain the usefulness of these from a practical standpoint. In addition, it will enlighten the perspectives of agile in practice and determine the essentials from a managerial view.

2.1.3.1 Control processes within agility

Control processes within agility are presented as mentioned to monitor and control flow. As established in section 2.1.2.2 tools are essential for controlling this flow and ensuring iterations proceed smoothly.

Agility is as mentioned a product of the information age and the advent of a significant increase in software development (Rigby, Sutherland and Takeuchi, 2016). This has led to multiple frameworks specifically catered towards the development of software both before the creation of the agile manifestos in 2001 and after. However, this specific targeting towards software development is no longer the case, a paradigm shift has happened, catering agility towards the broader organization, rather than just in the software-centric parts of the organization (Zielske and Held, 2021).

Different applications of agile have therefore become prevalent in organizations around the world. Scrum and eXtreme Programming being some of the most prevalent examples of frameworks either developed directly by the 17 industry leaders that created the agile manifestos or consultancies taking up the agile legacy and targeting it towards a specific purpose (Hummel, Rosenkranz and Holten, 2013). In general, there is a consensus that these frameworks are built using the same foundation, keeping an agile mindset, the 4 values, and the 12 principles of the agile manifestos. What changes however is the practices used in the separate frameworks, some specifically catering towards more lean-centric tools e.g. Kanban-like boards for monitoring progress are especially prevalent applications of lean specific tools within agility (Wang, Conboy and Cawley, 2012). With boards and other monitoring tools providing the opportunity to continually, monitor the progress of a project, and respond to change as necessary. An example of a control process from within Scrum product backlog to map task or requirements that are to be completed in the future and the sprint backlog mapping the chosen requirements for the current iteration of work being conducted, in addition to mapping the current progress of said requirements (Kussunga and Ribeiro, 2019).

Another essential control process is the value-centric approach with the customer and the costumers' feedback at the center of the requirement specification and extrapolation (Beck *et al.*, 2001). Especially, when considering that a fundamental value of agility is the disuse of contracts and typical legal discourse, rather than choosing to base requirements and work to be done on the collaboration with the customer (Napoleão *et al.*, 2021).

All of the above mentioned are examples of processes and tools within the domain of control that provides means of monitoring progress and ensure that the flow is smooth. Hence, from a management perspective, the application of these tools and processes to control the project or organizational change should present benefits and value generation for a development team, department, or organization. Furthermore, it should also present a modicum of risk control, as the iterations and alignment with the customer requirement provide the benefit of cost control, both concerning time and money (Walker, 2012).

2.1.3.2 Work processes within agility

Work processes as established is one of the three processes highlighted concerning agility in this paper. The specific application of the work processes varies from the different agility-centered frameworks; however, certain practices within these frameworks are aligned throughout with a basis in the agile manifestos and the historical methods predating it. First off, the implication that agility is an all-or-nothing approach is not true (Qumer and Henderson-Sellers, 2008). Meaning it is possible to implement agility in parts of the organization and not in others. With that potentially even being beneficial as agility demands conscious effort from the participants (Zielske and Held, 2021). Especially, when an expectation to adhere to the agile mindset is part of the implementation of agility. In practice few organizations can adhere to all parts of the agile mindset and the values, within a short period, an actual transition typically taking a few years (Qumer and Henderson-Sellers, 2008).

An important distinction when working with agility especially from the perspective of leadership and management is that agility is considered a "people" centered approach (Whitworth and Biddle, 2007). Meaning that the responsibilities of leaders and managers in their governance of the teams working within the agile paradigm are to ensure that the workers hold up the agile values, and use the principles to their utmost. Especially, with the focus of agility-centered work processes being on self-managing teams, with a servant-leader attached. In general, it could be said that agility enables the individual so that the effectiveness of the team increase (Tessem, 2014). The role of servant-leader is to ensure that the team practicing agility facilitates and discovers their definition of agility. The servant-leader is in large part the voice of the team to the rest of the organization, ensuring that the organization embraces the teams' agility

(Whitworth and Biddle, 2007). Furthermore, the servant-leader also ensures that the development team understands whatever practice or framework is implemented in the organization (Project Management Institute, 2017).

Another important characteristic of work processes within agility is the iterative nature that has been mentioned multiple times in this paper. Iteration allows for the work to be conducted in small time segments that range in scale from method to method, but in general, the consensus for small development teams is 1 to 4 weeks increments (Maruping, Venkatesh and Agarwal, 2009). This allows for continuous optimization towards customer requirements, in addition to allowing the stakeholders to change or influence the development whenever an iteration has ended. Further, it gives way for process optimization for the development team, with things that did not and did work within the last iteration being addressed at the end of a segment, ensuring continuous improvement (Walker, 2012). Thus, the work processes within agility are centered around the people and the structure of how results related to creating value for the customer is achieved. Through either the structuring of iterative development loops or ensuring that the values of agility are understood in the team and the organization. This realization should enable through management, leadership, and governance activities of the work processes to obtain results with agility and provide the environment for the individuals performing the work that ensures effectiveness and flexibility.

2.1.3.3 Knowledge processes within agility

The last essential process to further cover is knowledge, being a key denominator for ensuring the right work is completed based on customer collaboration and subsequent requirements and user stories. The iterative nature of agile allows for quick changes and feedback sessions at the end of an iteration, thus enabling continuous learning for individuals (Napoleão *et al.*, 2021). This ensures that the knowledge processes within agility are conducted clearly and concisely which is especially relevant from a management, leadership, and governance perspective. The specificities related to the essential nature stem from the fact that knowledgeable workers and individuals are the backbone of an organization and development process, especially when considering self-managing teams being stable of agile (Maruping, Venkatesh and Agarwal, 2009).

Several processes, such as planning boards and product backlogs, which have both previously been mentioned, are notable in the agile-centered frameworks regarding knowledge processes. Both examples are essential for tracking user stories, another significant knowledge process. User stories essentially determining and outlining the requirements of the customers (Zaina, Sharp and Barroca, 2021). User stories are typically facilitated and managed by the product owner, a management role that is responsible for guiding the direction of the product in development or the process of applying agility. The product owner typically works with the team, stakeholders, and customers to ensure that the product is moving in the right direction and that the knowledge within the team and potential from around it are applied in a sufficient manner (Zielske and Held, 2021). The work of the product owner is one of the key reasons for the decrease in documentation as the continued work with the customer allows for cooperation rather than contract negotiation, one of the values of agility.

Another significant process for ensuring knowledge is applied rather than extensively documented and going unused is the cross-functional team members. This means that a team should consist of members that ensure that an iteration of development can release a working piece of product. An example from a software perspective is that a team should comprise developers, designers, testers, and any other required role for the specific development process. In short, the knowledge processes within agility-centered frameworks are bound to the people and their interaction with the process. However, certain practices do help plan, track, and measure progress during the application of agility. Thus, the theoretical fundamentals of knowledge processes are to ensure that individuals work and interact with the team and the software rather than extensively document the process (Cram and Marabelli, 2018). This should be the goal of the management involved, enabling the individuals to work on the project rather than do unnecessary documentation.

2.1.4 Discussion

Regarding the content of the paper, agility is not just a software development tool any longer but a significant movement within organizational planning, project development, and management theory. Agility provides inspiration and change to operational companies and software developers alike. Hence, when investigating the theoretical fundamentals of agile, the perspectives that the three processes of control, work, and knowledge can provide management, leadership and governance are substantial. This substantiality stems from the understanding that if the fundamentals can be used and applied in a meaningful way, it could provide benefits regarding flexibility and effectiveness. Especially, if traditional project management is the benchmark. However, the authors do understand that agility is not the end all be all for an organization, different companies demand different needs. What is the argument, however, is that the droplets of agility that can be applied in certain manners, whether that is iterative methods or specific practices relating to work, control, or knowledge processes, would be beneficial to the organization embarking on an agile journey.

Thus, considering that agile is a dominating and difficult tool to work with, opinions regarding the field of study and the practical application of it are many. Hence, it is understandable if it is deemed unreasonable to implement agile because of these implications, however, the benefit towards efficiency and flexibility enhancements are tangible and should be considered.

2.1.5 Conclusion

Understanding the three processes and their parts is the first step towards working with agile or applying parts that contextually fit a given organizational situation. No two organizations are alike; hence, what is essential is to understand the value that agility can provide and enable so that individuals can shine through their work. Whether that is going full agile or implementing parts is inconsequential.

However, an important point derived from the first of the agile manifestos values is that individuals are central to most of the agile-centric ways, rather than focusing on processes and tools. This seems redundant when tools and processes have become an essential part of agile in its many forms however, what lies at the core of agility has proven to be a focus on iterative measures to allow for a fast response to change, ensuring value is created for the customer/stakeholder through extensive collaboration and providing individuals self-governing opportunities. Furthermore, the consideration of agility in the operational part of the organization further strengthens the focus on individuals and iterative measures. Some of the tools could and would be beneficial, but the context of the operational setup influences the usability somewhat. However, if a continued focus on the aspects highlighted, benefits in the operational parts of the operation will likely happen. Especially, as different parts of the operational aspects of the operations already have frameworks developed for them, Supply chain agility and Agile manufacturing being just two examples.

The practical implications of the three processes in the context of management and governance is specifically targeting the droplets of intrinsic value that can be found within the agile frameworks. Agility can be a large and comprehensive beast to tackle, with a significant amount of frameworks that empathize the agile values and principles in different manners existing in both literature and the industry. Thus, making choosing the correct framework or parts of one difficult for uninitiated individuals. Hence, this paper sought to examine the underlying structures and map the fundamentals to enable ease of access and understanding. To summarize and answer the research question, the processes of control, work, and knowledge are intrinsically linked with each other and agility, displaying theoretical fundamentals of agility in each process. At the core of the three processes is that individuals managing themselves and iteration serve as the enabling factors for agility, without either, working with agile processes would be difficult if not impossible.

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2.2 On Defining Industrial Agility as a Strategic Capability for Competitive Performance of Engineering Assets: An Industrial Eco-systems Perspective

The following conference article partly answers RQ1.

L. P. H. Brasen and J. P. Liyanage, "On Defining Industrial Agility as a Strategic Capability for Competitive Performance of Engineering Assets: An Industrial Eco-systems Perspective," 2022 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Kuala Lumpur, Malaysia, 2022, pp. 583-587, doi: 10.1109/IEEM55944.2022.9989959.

The published version of this paper can be found at this link: https://ieeexplore.ieee.org/document/9989959

The content of this subchapter is copied directly from this paper, with minor corrections due to formatting.

Abstract: In the last two decades the volatility and complexity of industrial dynamics, and subsequently uncertainties of asset-centric organizations, have increased challenging the risk and value profiles of asset owners and operators. Changing socio-economic, political and commercial circumstances increase the uncertainties of new and operating assets. In such industrial contexts, new perspectives are in demand in order to improve upon the strategic capabilities of asset-centric organizations. Amidst subsequently growing focus on modern collaborative solutions and new business models in some sectors, this paper explores, defines, and elaborates on the notion of industrial agility as a core strategic capability for continuous competitive performance when engineering assets are embedded within a dedicated industrial eco-system to deliver complex objectives.

Keywords: *Engineering asset management, Industrial agility and Industrial eco-system*

2.2.1 Introduction

Through the last two decades, the focus on Engineering asset management has increased significantly in industries around the world, particularly since the demands due to industrial dynamics and subsequently the inherent complexity of managing asset-centric organizations have been steadily increasing. The forceful effects of global industrialization, new financial exposure patterns, increase in new technology capitalization, developments in service markets, political effects, environmental pressure, and rise in knowledge demands, have been more observable than ever before. This has also led to a growing focus on sector-specific restructuring and new business models, as well as to resolve how strategic assets in a portfolio can develop unique capabilities to stay highly adaptive and flexible enough to be change-tolerant under dynamic and uncertain market conditions (Liyanage, 2017a, 2017b). This in turn exemplifies how industrial and market dynamics have begun to define new pre-conditions for engineering asset owners to be able to deliver competitive and sustainable industrial performance (Jakob E. Beer and Liyanage, 2017). However, with the increase in diverse commercial, political, socio-economic, and ICT related uncertainties in the current industrial landscape, a central query is to what extent an asset-centric organization can secure competitive capabilities to manage dynamic market demands and navigate through complex industrial conditions ensuring a competitive position and delivering consistently successful performance. This paper explores this further from an *Industrial agility* perspective, based on trends, developments, and lessons learnt in oil & gas production sector, major equipment manufacturing and service provision sectors, maritime industry, automobile sector, and digitalization of public sector (also see; (Liyanage and Langeland, 2008; Mckinsey, 2020; World Bank, 2021)).

2.2.2 Methods

This section outlines the research process undertaken to develop the key contribution of this paper, as depicted in Figure 2-1. The methodology consists of two primary components: a narrative literature review and a model development process. Each component is detailed below to articulate the research steps and justify the approach.

A structured narrative literature review was conducted to establish a foundational understanding of the topic and to inform the development of the model presented in Figure 2-1. The literature review encompassed diverse sources, including academic materials such as peer-reviewed journal articles, conference proceedings, teaching cases, and reports, which provided theoretical and empirical insights. Additionally, industrial standards, including International Organization for Standardization (ISO) guidelines, were reviewed to ensure alignment with best practices. To capture contemporary industry trends and real-world applications, media sources such as newspapers, industry articles, and press releases were also examined. The rationale for adopting a narrative literature review approach was based on the need for a broad, integrative synthesis of existing knowledge across multiple disciplines (Baumeister and Leary, 1997). This approach allowed for the identification of key themes, gaps, and trends, which were instrumental in shaping the conceptual model. The review process followed systematic steps, including keyword-based searches using keywords such as: *("Asset management", "Agile Manufacturing", "Engineering Assets" and "Industrial Ecosystems")* in academic databases *(SCOPUS, ScienceDirect and Google Scholar)*, citation tracking, and iterative refinement based on relevance and rigour. To exemplify, one of the used search strings would be structured as follows: *("Asset management" OR "Engineering Assets") AND ("Agile Manufacturing")*.

Parallel to the narrative literature review, an iterative and collaborative model development process was undertaken. This process involved structured workshops conducted with domain experts, researchers, and practitioners to co-develop the model. These workshops facilitated critical discussions, validation of concepts, and refinement of the model components to ensure that they aligned with both the industrial ecosystem perspective and the principles of industrial agility. The developmental cycle of the proposed model followed an iterative and participatory process designed to address the increasing complexity and volatility of modern industrial ecosystems. The model integrates theoretical constructs with practical insights, derived from multiple workshop sessions with academic peers. Each iteration of the model was refined to incorporate feedback, ensuring that it effectively captures the dynamic interplay of external factors, such as political and socio-economic uncertainties, and internal system capabilities, including flexibility and adaptability to shifting performance objectives. In addition to structured workshops, focused brainstorming sessions were held to ideate and evaluate different conceptual structures, strengthening the model's applicability and robustness. The iterative nature of these sessions ensured that the model evolved in response to expert feedback and theoretical grounding, progressively refining its usability and visualization. By systematically aligning the upstream, midstream, downstream, and vertical agility elements, the model highlights the interconnected and interdependent nature of industrial operations. The iterative development process ensured that the model encapsulates the mutual dependencies and systemic interactions necessary for achieving performance objectives while balancing risks and opportunities. By employing this dual methodological approach, grounding the research in existing literature while simultaneously engaging in an interactive model development process, this study ensures that Figure 2-1 is both theoretically robust and practically relevant. The iterative cycle underscored the importance of contextualizing industrial agility within the broader ecosystem to enable value creation, resilience, and competitive positioning.

2.2.3 Engineering assets and Emerging trends to deliver industrial demands

Although the interesting fields of assets and engineering assets have been the subject of research and practice for decades, a common understanding is still difficult to ascertain. Different definitions and interpretations of the terminology have evolved (C. Parra *et al.*, 2021). However, the definition of *what an asset* was defined somewhat clearly in 2014 when ISO published 55000 series of standards. These standards are currently being considered for practical implementation by various industrial sectors inclusive of infrastructure, energy, production, health care, etc. A general definition of *what an asset is*, can also be derived from the same standard i.e.; ''*an item, thing or entity that has potential or actual value to the organization*'' (ISO 55000 series, 2014, p. 2). This naturally encompasses everything generating value in an organization, which includes tangible, intangible, financial, and non-financial assets (ISO 55000 series, 2014; Liyanage, 2017a). This is equally relevant for engineering assets (Joe E. Amadi-Echendu et al., 2010), which include specific physical assets that are designed, engineered, and operated to enable business value creation for an organization through strategically acquired capabilities and resources (Jayantha P. Liyanage, 2003). Under relatively modern industrial contexts, these assets have more sensitive roles in serving an organization's complex and demanding performance objectives, ranging from monetary gains, dynamic market capitalization, new business opportunities, stochastic customer requirements, stakeholder engagement and compliance, and sustainability targets, to name a few. In spite of the common wisdom that contextualization of the terminology pertaining to modern assets, and in particular engineering assets, seems simplistic, a complex array of sub-layers and co-related strategic elements begin to appear when one is trying to determine the actual value and risk driven processes and complex performance profiles of these assets. This also strengthens the arguments that engineering assets gradually become unable to create value in their more traditional terms and forms without being embedded in a comprehensive industrial eco-system that should be relationally established co-operatively surrounding an asset or a portfolio of assets. The growing nature of uncertainties in operating and managing of such assets and portfolios in fact underlines the volatile new industrial reality. A whole range of complex combination of commercial, societal, technological, environmental, and even political factors forcefully influence and shape-guide the new value and risk exposure profiles of engineering assets demanding a higher degree of compliance from asset owners who have to deal with both complementary and conflicting performance objectives. The significance of this modern industrial condition is that the engineering assets created and operated with the goal of business value creation in more traditional manners, are in clear need of adaptive strategies sooner than later to strengthen their industrial position and market performance through a re-design of operational capacities and capabilities smartly capitalizing on internal, external, tangible, and intangible elements. Relatively new assets, on the other hand, possess unique opportunities to engineer, operate, and manage to fit to the new global and industrial order beginning from very early stages of asset life cycles with quite different value and risk management mechanisms and solutions. In both cases, new strengths and opportunities that are generated by emerging industrial trends and developments are unprecedented, and can out-weigh threats and weaknesses by substantial margins, provided that Asset owners are able and willing to embrace the powers of creativity and innovation pragmatically in terms of new business models, strategic partnerships, unique market capabilities, and agile resource pools.

2.2.4 Agility as an Industrial concepts and defining *Industrial Agility*

With the advent of the modern production systems up through the 1900s, a significant increase in the focus on creating more efficient manufacturing environments arose, where the focus on quality improvements and waste reduction were central. However, customer demand was likewise rising significantly, making it so that the manufacturing environments had to adapt to these rapidly changing market requirements. *Lean manufacturing* and *Agile manufacturing* represent two significant manufacturing philosophies developed amidst such demands (Esmaeilian, Behdad and Wang, 2016). Agile manufacturing is comparatively newer than Lean, emerging in the 1990s, (Nagel, Dove and Preiss, 1991; Shah and Ward, 2003; Esmaeilian, Behdad and Wang, 2016) and differing from Lean in that it centers on the rapidly changing requirements that exist within the market taking into consideration both volume and variety, meaning that the manufacturing environment should be scalable and changeable (Esmaeilian, Behdad and Wang, 2016). The significance of agile manufacturing cannot be understated and the impact that the agile methodology has had over the years on wider planning, development, and strategic choices is substantial. It is generally claimed that an agile manufacturing system can be operated profitably in a competitive business environment of continuous and unpredictable change (Hallgren and Olhager, 2009).

It is hereby argued that owing to foremost strategic developments in terms of smart technologies, ICT, digital services, etc., coupled with organizational restructuring as the means to overcome market uncertainties, agility is here to stay as [15] emphasize (Patricia M. Swafford, Ghosh and Murthy, 2006), even after three decades of its inception. Current performance dynamics of diverse industrial sectors(Patricia M. Swafford, Ghosh and Murthy, 2006), such as Energy production and distribution, Maritime, Public health, etc. provide ample of examples in this regard (Liyanage and Langeland, 2008; Mckinsey, 2020; World Bank, 2021). Due to the fact that the complexities of operating a modern industrial organizations, and hence engineering assets, are increasing due to increases in diverse commercial, political, socio-economic, and ICT related uncertainties in the current industrial landscape (Komljenovic, 2021), the flexibility, changeability and scalability, in which agility has a strategic role to the creation of business value is significant. To clarify the context of flexibility, scalability and changeability:

- Flexibility - refers to the ability to adapt processes and operations swiftly in response to changing requirements or market conditions. In agile manufacturing, this means quickly adjusting production methods to meet customer demands and market changes (Abdelilah, El Korchi and Balambo, 2018). Furthermore, in asset management, this could be referring to flexibility in management decision-making processes, embracing changing stakeholder demands and strategic choices.
- Changeability - This term emphasizes the capacity to fundamentally alter the structure, function, or purpose of a system. In agile manufacturing, changeability involves reconfiguring production lines for new products or processes (Ross, Rhodes and Hastings, 2008). In AM this could likewise refer to the physical configurability of the asset, to accommodate new strategic directions.
- Scalability - is the ability to efficiently expand or contract operations in response to demand fluctuations. In agile manufacturing, it ensures production systems can handle increased output without a proportional rise in costs (Ross, Rhodes and Hastings, 2008). In AM one aspect of

scalability is the ability to make the right decision regarding expanding or contracting the asset portfolio, i.e. balancing risk versus opportunities in changing market demands and operating conditions.

This arguably resembles the same principles that agile manufacturing is correlating to; "*providing costumer-driven products and services through the combination of reconfigurable resources, best practices and competitive bases"* (Routroy, Potdar and Shankar, 2015, p. 2), but in a different industrial scale and context within an eco-system, and thus enabling asset owners to better deal with uncertainties and complexities associated with their industrial operations. However, a review of various scholarly literature (see for instance (Patricia M. Swafford, Ghosh and Murthy, 2006; Gunasekaran, Yahaya Y. Yusuf, et al., 2018; Lucas Peter Brasen et al., 2019)) reveals that despite ongoing industrial trends and development, there is a lack of an agile interpretation that extends beyond agile manufacturing and encompasses the stochastic characteristics prevalent in the current industrial eco-system contexts, where the dynamics of asset operations and business performance are controlled by different dimensions (Jakob E Beer and Liyanage, 2017; Tsujimoto et al., 2018). Some examples of organizational agility, agile manufacturing, and agile product development covers some aspects relevant for industrial eco-systems and the demands within, however it is argued here that they are found lacking a holistically encompassing perspective of the entire industrial agility concept.

Based upon these trends, needs, and performance conditions thereof, it is argued in this paper that a definition of *industrial agility* need to be formulated as;

"Industrial agility is the ability to embrace flexibility, adaptability, and readiness for change or to meet stochastic industrial demands. Industrial agile companies embody the mentality that change is an inevitability and therefore are always prepared to capitalize on opportunities in the market, to respond to the changing dynamics of an industry proactively, and to gain a unique competitive position in terms of value and risk profile. Business models, processes, strategies, assets and partnerships are created and maintained to facilitate this mindset, creating a truly agile interface in an eco-system, that are renegotiable and reconfigurable to best-fit within the demands of the market, threats, and opportunities in industry, to better deal with performance uncertainties."

2.2.5 Industrial Agility as a strategic capability for modern Engineering Assets to deliver unique performance

Modern engineering assets are under increasing pressure due to a complex set of internal and external performance influence factors, and subsequently, a growth of complex demands towards the performance of these assets is prevalent. The complexities are a product of the increased diverse requirements that a modern industrial organization is subjected to. Unique issues such as global conflicts, supply chain crises, social uprise, market economy, etc. also have explicit or implicit influences that challenge the dependability and continuous ability of an engineering asset to operate and produce to realize stipulated performance objectives (Komljenovic, 2021).

The growing complexity, for instance of managing and operating manufacturing operations, has been well-documented by various scholars and practitioners globally (Liyanage, 2017a; Hastings, 2021). However, in the last decade globalization, technological advances, and macro-economic changes have created a significantly more volatile and complex environment that the engineering assets and the modern industrial organization must navigate. The inception of network-based organizations, industrial clusters, and dedicated industrial eco-systems, can arguably be attributed to these changing dynamics and change-inherent uncertainties of asset owners (Jakob E. Beer and Liyanage, 2017; Uusitalo et al., 2017; Valkokari and Rana, 2017; et al., 2018). Given the inherent challenges and the dynamic nature of industrial ecosystems, there is a compelling need to integrate industrial agility within existing asset management strategies. Ruitenburg, Braaksma and van Dongen (2016) highlight that an increasing number of physical asset owners and managers are confronted with evolving operational conditions that challenge traditional asset management practices. This is particularly complex as physical assets are typically designed for longevity and stability, while their operational environments are subject to continuous change. This phenomenon, termed the “agility paradox” by Ruitenburg, Braaksma and van Dongen (2016), underscores the tension between the static nature of physical assets and the necessity for agility in the processes, workforce, and organizational structures that support them. Consequently, while the assets themselves remain relatively fixed, the surrounding management systems must exhibit adaptability to ensure alignment with shifting industrial demands and uncertainties.

To understand these changing requirements, understanding the *industrial eco-system* as a concept is also a necessity. Traditionally, an industrial eco-system relates to the movement of material and energy to produce products (Tsujimoto et al., 2018). However, newer studies have emphasized a larger complex configuration of interconnected elements, where hardware, software, application, and service layers, surrounded by partners, investors, other influencers, and users make up the complex interactions that exist within an eco-system holistically (Valkokari and Rana, 2017; Tsujimoto et al., 2018). Furthermore, from an engineering asset perspective, it is argued here that an asset owner’s ability to deliver top performance through the competitive attributes of flexibility, adaptability, and readiness for change is in principle influenced and shape-guided by the nature and dynamics of these newly emerging eco-systems (also see (Hallgren and Olhager, 2009)). The Asset owner's creative and innovative abilities are instrumental within such an interconnected cooperative system to strengthen strategic market-oriented capabilities to meet complex industrial demands and deal with inherent uncertainties. Figure 2-1 is a visual representation of a simple epistemological overview of the main arguments raised here from an industrial agility and engineering asset perspective, derived from literature and industry experience. It highlights mutual interface levels within a generic industrial eco-system based on observations of recent developments, for instance, in the oil & gas production sector, maritime industry, automobile sector, and the public sector. The figure as detailed in the methods section was developed through an iterative development cycle that included multiple workshopping sessions configuring and finetuning the figure for usability and visualization.

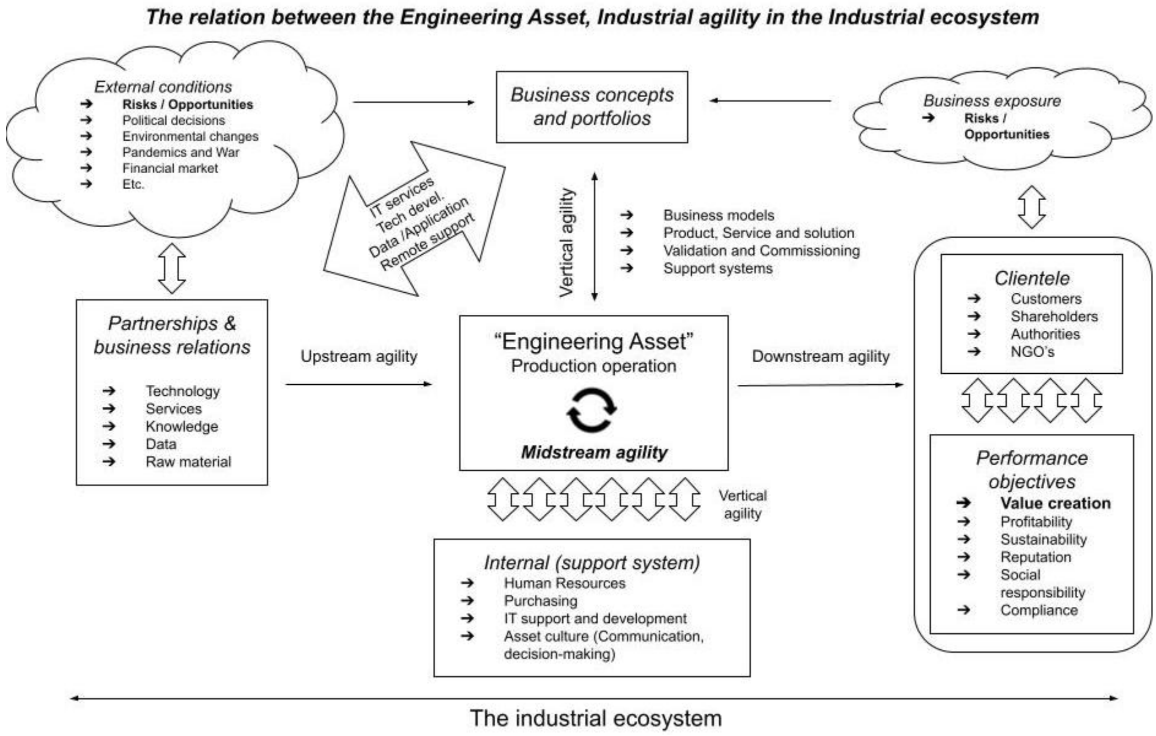

Figure 2-1 - The relation between the Engineering Asset and Industrial Agility from an Industrial Eco-system view

Figure 2-1. is, in large part, also inspired by a value stream map (Faulkner and Badurdeen, 2014a), embracing elements that impact or influence the business value creation in an engineering asset. Each directional block of agility is addressed concerning the issues that the overall industrial agility application should alleviate with particular emphasis on allowing further detailed analysis of critical success factors with which industrial agility embraces in a pragmatic sense. However, it is important to note that each specific directional block of agility is unlikely to be applicable alone due to their mutual inter-dependencies either explicitly or implicitly. In principle, the notion of Industrial agility can be represented as a fusion of both *vertical* and *lateral* perspectives. The notions of *upstream* and *downstream* agility can arguably be considered as a different take-on from the supply-chain view. The interlinked nature of the directional blocks is a necessary feature of the notion of Industrial agility as it is sensitive to defining to which degree to the performance objectives of an asset-centric company can be reached in an integrated and optimally balanced manner while managing risks and opportunities. The interplay between industrial agility in the upstream, downstream, vertical, and midstream perspectives towards Engineering asset management is correlated to, especially this risk and opportunity perspective. For instance, the point made by, Patricia M Swafford, Ghosh and Murthy (2006), that '*An agile enterprise is a fast-moving, adaptable and robust business. It is capable of rapid adaptation in response to unexpected and unpredicted changes and events, market opportunities, and customer requirements. Such a business is founded on processes and structures that facilitate speed, adaptation, and robustness and that deliver a coordinated enterprise that is capable of achieving competitive performance in a highly dynamic and unpredictable business environment that is unsuited to current enterprise practices (Patricia M Swafford, Ghosh and Murthy, 2006)'* the interconnectedness with the risk/opportunity-management centric Engineering Asset Management approaches. Further, the newest iteration of ISO 55001 deliberates that adaptation is a significant factor for asset management success (Patricia M Swafford, Ghosh and Murthy, 2006), thus further arguing for agile interplay.

The *Upstream agility* relates to upstream activities and influences through specific partnerships and business relations. The very ability to manage and control strategic relations and partnerships with suppliers and services, both flexibly and adaptively, is a crucial issue both from a risk and opportunity perspective. In many industrial settings, inherent uncertainties of technical or supply interruptions are on the rise, with direct effects on midstream and downstream performance levels.

The *Downstream agility* in contrast relates to downstream activities and influences towards the clientele and performance objectives. This is where the ability to respond to changes from the customer's or market perspective is also important. While the ability to sell a product or service at large defines the way how a company remains profitable, the enhanced ability to operate an adaptive, responsive and innovative business is equally crucial. This incorporates the understanding that changeability based on clientele and market performance data is critical, allowing the pursuit of new opportunities and even risks towards a stronger position.

The *Vertical agility* covers specific attributes that address unique top-down and bottom-up abilities based on industrial and market exposure. The top-down process covers attributes related to specific product solutions, business, and service development, validating and commissioning of solutions, etc. which provide the basis for the expected degree of flexibility, changeability, and reconfigurability of operations in an engineering asset. The activities related to new business concepts and portfolio development are also part of vertically agile efforts. The bottom-up process involves operationally sensitive internal issues and conditions. Specifically, HR, IT support and development, purchasing and warehousing, and even asset-specific culture to mention a few. The real performance effects of these issues can often remain under-calculated and can become unexpected hindrances.

The *Midstream* agility can be considered equivalent to that of agile manufacturing where operational aspects within engineering assets play central roles. Midstream agility centers on the flexibility, and reconfigurability of an engineering asset and its technical and operational processes. To exemplify this through the lens of EAM reconfigurability relates to the reconfiguration of the physical assets to accommodate to changing market demands (Bruccoleri, Pasek and Koren, 2006), whereas flexibility in this context correlates to the changing individual operations, processes and parts to accommodate for a set scope of a defined varied-parts setup. Further, in a production or manufacturing contexts, many bottlenecks can exist when an asset owner plans to implement new solutions with reference to customer requirements, and market trends.

When capitalizing on industrial agility as a strategic capability, contextualizing the model developed is imperative to enhance understanding as to how the pre-defined and un-defined critical success factors play sensitive roles, and even what should be considered and what should be down prioritized. It is specifically so, when the ability to embrace flexibility, adaptability, and readiness for change represents a highly diverse set of critical attributes to meet the requirements and demands of the industry exposing an asset owner to a range of risks and opportunities. Industrial agility enables capitalizing on a robust eco-system with the understanding that change is inevitable and thus asset owners should always be prepared to pursue opportunities and risks duly, with the primary goal to create business value and to ensure the accomplishment of complex industrially sensitive performance objectives for a competitive industrial position.

2.2.6 Conclusion

This paper explored, defined, and elaborated on the notion of *industrial agility* as a core strategic capability for continuous competitive performance when engineering assets are embedded within an industrial eco-system to deliver complex objectives. Industrial agility and engineering assets become seamless when these assets are engineered and operated towards flexibility and changeability, which represent the same values that the agile mindset is centered around. The capability to be adaptable and flexible is critical in increasingly volatile and complex markets, which is affected by diverse commercial, political, socio-economic, and ICT-related uncertainties. The contextualization of Industrial agility should enable the identification of critical attributes of performance concerning the risk and value profile of an asset-centric organization, and thus implementation of early measures for strengthening competitive performance and market positioning.

Future research and validation

While this study has developed and contextualized the model presented in Figure 2-1, further empirical validation remains an essential next step. The validity of the model beyond its conceptual development has not yet been extensively tested in real-world industrial settings. Future research should focus on applying the model in various engineering asset management contexts to assess its practical feasibility and effectiveness. Possible validation approaches could include conducting in-depth case studies with industry partners which will provide valuable insights into how the model functions in different organizational environments. Additionally, utilizing both quantitative and qualitative data collection methods will allow for a comprehensive assessment of the model's impact on industrial agility and business value creation. Furthermore, benchmarking against existing frameworks will help identify the model's strengths, limitations, and areas for refinement, ensuring its continued development and relevance in engineering asset management. Such validation efforts will contribute to enhancing the robustness and applicability of the model, ensuring its relevance for organizations aiming to optimize industrial agility within engineering asset management.

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3 Chapter 3. – Digitalization and EAM

This chapter comprises two publications that examine different dimensions of digitalization within the context of maintenance, asset management, and data maturity. Together, these studies contribute to answering RQ2, exploring how digitalization intersects maintenance strategies and broader asset management practices.

The first publication, *Comparison between Data Maturity and Maintenance Strategy: A Case Study*, investigates the relationship between a company's data maturity and its maintenance strategy through four case studies and a comprehensive literature review. The study defines data maturity as an organization's ability to effectively plan, collect, process, enrich, and utilize IoT-related technologies for decision-making and operational efficiency. It highlights the critical connection between predictive maintenance strategies and the level of data maturity required for their successful implementation. By introducing a new framework, this publication offers insights into decision-makers on aligning operational performance with data-driven maintenance and asset management.
The second publication, *Exploration of Digitalization and Digitalization Indicators within the Scope of Asset Management*, further explores digitalization specifically through the lens of perceived maturity within asset management. This study establishes both a theoretical and practical foundation for digitalization through a theoretical foundation build on a narrative literature review and an industry-wide questionnaire involving 66 professionals from Danish companies. The findings suggest that, despite Denmark's strong reputation for digitalization, many organizations exhibit considerable variability in their digital maturity, with significant gaps between theoretical advancements and actual industry practices. The study underscores the challenges companies face in effectively integrating digital technologies into their asset management strategies.

While both studies focus more heavily on maintenance and maintenance management than on asset management, their inclusion in this dissertation is justified for several reasons. First, although maintenance and asset management are conceptually distinct disciplines - differing in methods, scope, and terminology - the practical reality among industry practitioners often blurs these distinctions. Over nearly four years of engagement with a community of practice in asset management, it became evident that many professionals in the field view asset management and maintenance as closely intertwined, if not synonymous. In practice, asset management is often equated with specific, asset-related activities, primarily maintenance operations. While academia differentiates between asset lifecycle management, risk-based decision-making, and maintenance execution, practitioners frequently perceive asset management as a function directly influencing maintenance strategies. Second, despite the conceptual differences, both asset management and maintenance involve direct interaction with physical assets, making digitalization a crucial enabler in both domains. Digital technologies facilitate enhanced decision-making, risk assessment, and lifecycle optimization, particularly through real-time data analytics, IoT-enabled sensors, and predictive maintenance models. These advancements directly impact how organizations prioritize maintenance activities and optimize asset performance. Thus, the integration of these two studies within this dissertation serves a dual purpose: (1) demonstrating how digitalization transforms maintenance management and (2) using these insights to argue for a reconceptualization of asset management through digitalization. By highlighting the practical realities of maintenance and digital transformation, these publications contribute to a broader understanding of how digitalization can redefine asset management frameworks in modern industrial contexts.

The content of the chapter is directly copied from the papers, with some corrections needed due to formatting and context needed in the papers.

3.1 Comparison between data maturity and maintenance strategy: A case study

The following conference publication partly answers RQ2:

Lucas Peter Høj Brasen, Oliver Fuglsan Groos, Torben Tambo, Comparison between data maturity and maintenance strategy: A case sutdy, Procedia CIRP, Volume 104, 2021, Pages 1918-1923, ISSN 2212-8271, https://doi.org/10.1016/j.procir.2021.11.324.

(https://www.sciencedirect.com/science/article/pii/S2212827121012221)

The published version of the paper can be found at this link: https://www.sciencedirect.com/science/article/pii/S2212827121012221?via%3Dihub

The content of this subchapter is directly copied from the paper, with minor changes due to formatting

Abstract: From Industry 4.0 there has been a substantial drive towards sensor networks for enabling predictive maintenance as essential in asset management. This paper analyze sensor data maturity and asset management strategy. A model is proposed for establishing a best-fit correlation between data maturity and maintenance strategy both as for the current situation and guide for future development. The findings are based on literature and case studies in the SME segment. Research implications are to view enterprise strategy as a balance between chosen maturity and operational needs. Practical implications are the possibility to sustain or improve and qualify investment planning.

Keywords: *manufacturing; asset management; data maturity; sensor networks; predictive maintenance; Internet-of-Things; SME*

3.1.1 Introduction

With the advent of Industry 4.0 in the early 2010's, the progression of Asset Management (AM) and maintenance have been brought into the 21st century (Bousdekis *et al.*, 2019). The proliferations of Internet-of-Things (IoT) especially real-time sensors in the production environment have increased the data collection, which in turn have generated larger data loads. This have increased the potential for analysis and better decision-making in the production environment (Arjoni *et al.*, 2017). This progression in data maturity in the production sector have increased the likelihood of identifying and performing repairs on the production equipment before corrective maintenance is necessary (Candón *et al.*, 2019).

The act of maintaining a production line is however, not singularly dependent on the maturity of data, the approach and implemented maintenance strategy likewise have a significant impact on the effectiveness of the maintenance, which correlates to potential breakdowns. However, to better understand the correlation between data maturity and maintenance strategy, the purpose of this paper is to investigate through case studies how Danish SME's conduct their maintenance and the overall level of data maturity. Through the modelling of the SME's systems architecture and the knowledge collected from the literature a correlation matrix is created, with the aim of educating and influencing better decision-making regarding maintenance strategy and Industry 4.0 implementation.

3.1.2 Literature review

The literature review is centered on asset management and especially maintenance terminology, in addition to data maturity and data maturity models in the perspective of IoT and Industry 4.0.

3.1.2.1 Asset management and maintenance

Industry 4.0 has been highly influential on the current research in maintenance and in turn asset management (Love and Matthews, 2019). The impact of Industry 4.0 in asset management and maintenance ranges from improved operational and production planning to maintenance management and governance. This is all based on collected data at hand and associated algorithmic approaches for better operational planning of maintenance activities. In turn, algorithms based on data collected from the production control system and sensor networks (Bousdekis *et al.*, 2019). Predictive maintenance planning should ensure a production with assets that have a low probability of errors, which in turn increases production output and efficiency (Overall Equipment Efficiency – OEE) (Ferreira *et al.*, 2017). However, this approach is not a fit for all companies as significant efforts are necessary for the implementation of a predictive maintenance setup (Lins *et al.*, 2018). This is just one approach to asset management in a maintenance perspective. However, to ensure that the terminology regarding asset management is consistent, this paper uses the definitions from ISO 31000:2014; The factors which influence the type of assets that an organization requires to achieve its objectives, and how the assets are managed (DS/ISO, 2014). These definitions and approaches are used throughout the paper to ensure a common understanding in the analytical work that follows.

3.1.2.2 Maintenance types

Generally, maintenance can be divided into different types which according to CEN 13306:2017 is of two primary capacities either preventive or corrective maintenance. Preventive maintenance being maintenance that is carried out to assess and/or lessen the breakdown and likelihood of failures in an asset (DS/ISO, 2017). Meaning that maintenance carried out in this manner is only relevant and meaningful if the maintenance reduces the likelihood of failures and breakdowns. When discussing preventive maintenance, two general sub types exist, condition-based maintenance and predetermined maintenance. Condition-based is maintenance conducted based on assessments of the physical condition and analysis of the asset. Whereas predetermined maintenance is carried out in terms of intervals e.g. number of uses or active time.

Predictive maintenance is considered a sub-type of condition-based maintenance, with it being maintenance that is carried out according to a forecast generated from repeated analysis, known characteristics and the evaluation of significant parameters.

Corrective maintenance on the other hand is maintenance that is carried out when a fault in the asset is recognized and is intended to restore the asset to a state that it once again can perform its required function (DS/ISO, 2017). Meaning when an asset breaks down and fails to perform its intended function and have to be brought back to functionality that is corrective maintenance. The maintenance sub-types for corrective maintenance is deferred corrective maintenance and immediate corrective maintenance. Deferred corrective maintenance is corrective maintenance that is carried out at a later day in accordance with regulations, whereas immediate corrective is carried out right away.

The use of CEN 13306:2017 as the key determinant for defining and categorizing the maintenance types stems from the industry recognition the standard receives, in conjunction with the widespread usage of the standard in the industry. Figure 3-1 highlights the maintenance terminology and the different sub-types maintenance can be defined as. The figure is a construct based on the terminology presented in CEN 13306:2017 and the correlation that is between the different types of maintenance.

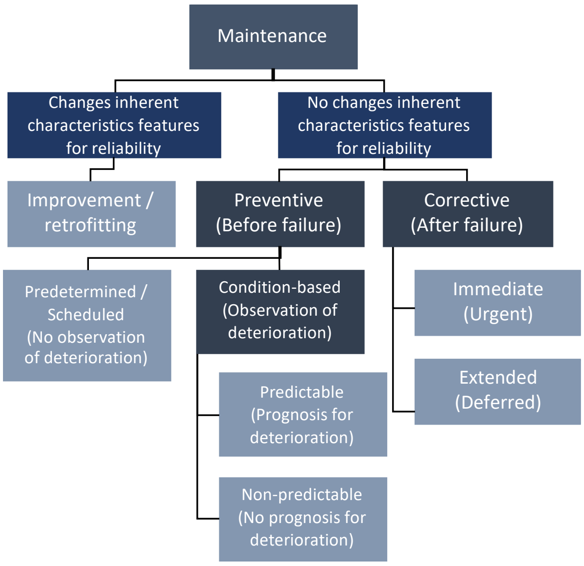

Figure 3-1 - Overview of Maintenance terminology and the interconnectedness of the terminology

3.1.2.3 Data maturity

Data maturity relates to an organization's capability to effectively manage, leverage and utilize data (Comuzzi and Patel, 2016; Langer, 2025). Maturity models are useful tools for analyzing as-is situation and controlling to-be situations within different domains (De Bruin *et al.*, 2005). A maturity model consists of sequential steps that each represent different anticipated or desired maturity levels. The purpose is to illustrate a typical evolutional path of these objects (Becker, Knackstedt and Pöppelbuß, 2009). To exemplify a generic data maturity model should serve as a framework to assess and guide an organization's data capabilities.

Its primary purposes include: a*ssessment* - evaluating current data management practices and identifying areas for improvement, *benchmarking* - comparing data capabilities against industry standards or competitors, *roadmapping* - providing a structured path for advancing data practices to achieve higher maturity levels and *risk management* - identifying potential data-related risks and establishing governance to mitigate them (Langer, 2025).

Becker et al. (2009) proposes a maturity model development tool for IT managers and develops an IT performance measurement (ITPM) maturity model in that process. The model is based on existing maturity models from the literature and developed using domain experts and the Delphi method. The model proposes the maturity model based on three dimensions: Contents, Organization and Technology. The Technology dimension represents the technological aspects of performance measures such as standardization, automation and integrations. The Organization dimension represents organizational governance and capabilities. Lastly, the Contents dimension measures the relevance of the ITPM solution in context of the IT department, including awareness, coverage and purpose. The model includes an extra initial level, that represents complete non-existence of ITPM. Unlike some others, this model introduces an initial level that represents complete lack or non-existence of ITPM, as proposed by Becker (Becker, Knackstedt and Pöppelbuß, 2009).

At the time of writing this paper, there is a considerable lack of data maturity models in the academic literature. The same is concluded by Comuzzi and Patel, who points to existing models being primarily developed by the consultancy industry, which limits the models' internal validity, as they do not provide the background for the models (Comuzzi and Patel, 2016). Comuzzi and Patel (2016) themselves develop a Big Data Maturity Model, based on literature on development of maturity models, the industry-developed maturity models and domain experts. Being focused on Big Data as a comprehensive technology, their model factors in five domains within strategy, data, organization, Governance and IT infrastructure. Strategic alignment evaluates how Big Data is exploited in the corporate strategy. The organizational domain considers people and culture in two sub-domains, that evaluates employee's awareness and capabilities of Big Data and the cultural recognition and trust of Big Data. Governance evaluates the extent of organizational structures and processes to manage and exploit the potential of Big Data (Comuzzi and Patel, 2016). According to Comuzzi and Patel (2016), Governance and Organization is separated domains, as Governance refers to formal structures and the latter refers to individuals' subjectivity and organic interrelations. The data domain covers both the processual management of data, in terms of lifecycles and treatment of the data, and analytic capabilities, that focus on the understanding of the knowledge that the data provides to the organization. Lastly, the IT domain covers infrastructural subdomains that focuses on the technical acquisition and management of the data. The maturity is measured in five levels as proposed by Becker et al. (2009), on which an extra Level 0 is introduced to represent a complete lack of capabilities (Comuzzi and Patel, 2016). The paper does not describe the actual names of the levels for each domain but describes the meaning of them individually.

In a paper by Parra et al. (2019), a rather comprehensive data maturity model is proposed. This model aims to measure companies' use and quality of data, data infrastructure and organizational capabilities regarding data (Parra *et al.*, 2019).

Król and Zdonek, 2020 presents an analytics maturity model by synthesizing existing maturity models identified through a literature review. The reviewed models stem from both academia and acknowledge technology advisories such as Gartner. The authors do not treat dimensions under the different models, only the maturity levels (Król and Zdonek, 2020).

Also, Cosic et al. (2012) presents a maturity model that is based on previous work, among others Becker et al. (2009) (Becker, Knackstedt and Pöppelbuß, 2009; Cosic, Shanks and Maynard, 2012), to which the model is also similar. The model measures the overall business analytics maturity based on four dimensions: Governance, Technology, Culture and People. These dimensions are concatenations of 16 low level BA capabilities deduced from a literature review on Information System literature.

Lastly, Spruit and Pietzka presents a maturity model for master data management defining this as "describing the most relevant business entities, on which the activities of an organization are based..." (Spruit and Pietzka, 2015). Spruit and Pietzka suggest a maturity model and uses their definitions to define the levels of the model. However, they exclude the initial non-existent level, as non-existent maturity should not be measured. The maturity model is organized around five areas that overarches 13 focus areas: Data model, Data quality, Usage and ownership and Data protection (Spruit and Pietzka, 2015). Table 3-1 summarizes these findings on the different perspectives in the examined maturity models.

Table 3-1 - Maturity model overview

Maturity Model	**Dimensions**	**Maturity Levels**	**Unique Features**
Król & Zdonek (2020)	Analytics stages (Descriptive, Diagnostic, Predictive, Prescriptive, Cognitive)	5 levels, based on analytics progression	Focuses on analytics progression path and real-time enterprise transition
Comuzzi & Patel (2016)	Strategy, Data, Organization, Governance, IT Infrastructure	6 levels (including Level 0 for non-existence)	Addresses both technical and managerial aspects; evaluates the impact of Big Data across the entire organization
Becker et al. (2009)	Contents, Organization, Technology	6 levels (including Level 0 for non-existence)	Structured framework for IT management maturity; utilizes the Delphi method
Parra et al. (2019)	Data Availability, Data Quality, Data Analysis & Insights, Information Use, Decision-Making	Stages from uninitiated to fully embedded	Holistic approach tailored for SMEs; emphasize systematic competency evaluation
Cosic et al. (2012)	Governance, Technology, Culture, People	Not explicitly specified	Based on 16 low-level business analytics capabilities; integrates governance and organizational culture
Spruit & Pietzka (2015)	Data Model, Data Quality, Usage & Ownership, Data Protection	5 levels (excludes Level 0)	Maturity matrix with 13 focus areas; emphasizes structured data integration processes

3.1.3 Methodological approach and case studies

To examine the technological landscape and maintenance workflows within SMEs engaged in physical production, semi-structured interviews were conducted with representatives from four case companies. Each interview lasted between 30 to 45 minutes and was conducted either on-site or via telephone. A follow-up via email was conducted to validate the collected information. The sampling approach was primarily based on convenience and participant willingness to engage in discussions regarding their production environments, data management, and maintenance activities. Companies were initially contacted through cold-calling with the phone numbers being sourced from webpages or available online information, though a significant number of calls declined participation or provided incomplete responses. The four selected cases were chosen based on their willingness to engage in more detailed discussions, allowing for a more comprehensive exploration of the research themes.

The interviews followed a semi-structured format, allowing for open-ended responses while ensuring that key themes were addressed. A predefined interview guide was developed based on literature on industrial digitalization and maintenance strategies. The guide covered areas such as existing technological infrastructure, production processes, and challenges in maintenance operations. Each company was represented by one key respondent, typically a manager or an engineer with direct involvement in production and maintenance processes. For companies that were visited on-site, the interviews were complemented with direct observations, including a guided tour of the production facilities. This enabled contextualization of the collected data by assessing the current level of data usage and maintenance approach. The data collected from the interviews were documented in the form of meeting notes, which were reviewed and analyzed after the interviews were conducted. To ensure a structured approach to data interpretation, thematic coding was applied. The coding process was guided by two primary themes that emerged as particularly relevant to the study: data usage and maintenance approach. These themes were selected based on their prominence across the collected data and their alignment with the research objectives. Thematic coding allowed for the systematic identification of patterns and insights related to how companies utilize data in their production environments and the strategies they employ for maintenance. Cases are summarized in table 3-1.

3.1.3.1 Company A – injection molding and toolmaking ~ 90 FTE

Company A is an injection molding company with ~90 employees, where around 15-20 is white collars. There are two primary lines of business: Toolmaking and injection molding. In the toolmaking, the injection molds (IM) for the production equipment, are developed. When a customer requests a plastic part, they first must develop an IM to cast the part. The production has 45 IM machines, which are primarily positioned in a cell layout. Every machine works independently producing parts using whatever IM is in the machine. The IM technically belong to the customer, but is kept in storage, used and maintained by Company A. This means that Company A not only has to maintain the production equipment, but also the IMs. Most molds are serviced when operators notice variations or defects in the production. They currently have no business analytics capabilities but are in the process of introducing it gradually.

3.1.3.2 Company B – Agro automation ~ 100 FTE

Company employs around 100 people and manufacture products for livestock farming, mainly robotics. According to the factory manager, the production consists of 50 machines divided into five departments. Most machines are CNC-based processors of metal items of different ages and brands. The run-to-failure strategy is chosen as they have enough capacity to relocate the production to another machine, should one break down. The company does not plan to develop the maintenance strategy in the future, nor do they plan to use data to optimize production and maintenance, as they do not see the need for it.

3.1.3.3 Company C – Transmission components ~ 120 FTE

The main production consists of approximately 75 machines, including routers, lathes, grinders and hardeners - most of them are CNCs. The machines are placed in a cell layout and the company primarily produces by customer-specific orders. The company works with maintenance on different levels. The oldest production equipment dates back to the early 1950s and has been updated and retrofitted over the years to accept newer control interfaces. They have employed professional data analysts to interpret the data and develop optimization projects from it. Currently the company also participates in research activities with a university and research center to retrofit IoT devices on production equipment to forecast downtime and future repairs.

3.1.3.4 Company D – Textile sub-component ~ 45 FTE

Experience has proved that some of the ovens used in the production should be shut down, taken apart and serviced twice a year. However, this is approximated and not rigorously scheduled. The company is currently going through some development on this area, where service and maintenance is moving from chaotically "putting out fires" to a more organized structure. The problem can often be traced back to lack of communication between production planning and maintenance. Furthermore, the experience-based maintenance also means that there is no formal system to manage the maintenance in, making the entire process very fragile. This results in production running when maintenance has planned services and vice versa.

Table 3-2 - Overview data and maintenance case companies

Case	***Data usage***	***Maintenance approach***

A	Some mechanical counters on the molds otherwise visual experience based inspections. No storage or collection of data and no electronic monitoring.	Semi regular maintenance typically based on run time or intervals of 14 days or more.
B	Does not collect or use data from their production.	Only governmental mandated service and maintenance otherwise run to failure.
C	Collects data from all production equipment, and uses it actively, for e.g. OEE calculations.	Differentiated maintenance dependent on the age of the production equipment. The manufacturer maintains Service on new sophisticated machinery as it is too difficult for the company C. Typically service intervals of 6 to 12 months or based on active production hours.
D	No systematic approach to data collection. Very individualistic planning done based on experience, rather than data.	Few pieces of equipment with a somewhat scheduled maintenance approach. Otherwise, mainly experience and intuition-based maintenance.

3.1.4 Analysis

The effectiveness of maintenance strategies within SMEs is influenced not only by the maturity of their data infrastructure but also by the specific maintenance approaches they implement. While data maturity determines the extent to which an organization can collect, manage, and utilize data for decision-making, the chosen maintenance strategy dictates how maintenance activities are planned and executed. Understanding the interplay between these two dimensions is essential for improving maintenance efficiency and guiding Industry 4.0 adoption. This chapter presents an analysis of data maturity and maintenance strategy, derived from both literature and case study findings. These dimensions were identified as key factors based on their strong presence in the literature on predictive maintenance and asset management, as well as their significance in the case studies conducted for this research. Data maturity is categorized based on technological capabilities, organizational readiness, and governance structures that support data-driven maintenance. Maintenance strategy, on the other hand, is classified into three broad approaches: ad hoc (corrective), predetermined (scheduled), and condition-based (data-driven or experience-based).

To systematically assess the relationship between these dimensions, a comparative matrix is developed. This matrix serves as a diagnostic tool to evaluate the current level of maintenance strategy and data utilization within an organization. The expected outcome is a structured framework that enables SMEs to determine their aggregate maintenance and data maturity levels, facilitating informed decision-making regarding future investments in maintenance strategies and digital transformation initiatives. By aligning maintenance practices with data capabilities, organizations can enhance operational efficiency and optimize resource allocation for Industry 4.0 integration.

3.1.4.1 Data maturity dimension

The development of the proposed model will undertake a similar process as described by Becker et al. (2009) and Król & Zdonek (2020), where previous proposed models synthesized to form a new. Despite the models in section 2.2 focusing on different areas, such as IT Performance Measures (Becker, Knackstedt and Pöppelbuß, 2009), Big Data (Comuzzi and Patel, 2016), Master Data Management (Spruit and Pietzka, 2015), and general data maturity (Parra *et al.*, 2019) there is some level of consistency among these domains. These consistencies have been summed up in three categories, mainly adopted from Becker et al. (2009): Technology, Organization and Management. Technology covers the technical facilitation of data and

generally covers data availability through data sources and IT infrastructure, and the quality of the data itself (Spruit and Pietzka, 2015; Comuzzi and Patel, 2016; Parra *et al.*, 2019).
Inspired by Comuzzi & Patel (2016), Cosic et al. (2012), and Becker et al. (2009), Organization covers the organizational facilitation of data, generally assessed from a capability and culture perspective. In terms of capability, the focus is on the analytical skills in the organizations and the (technological) ability to analyze and understand the data to utilize it for decision-making and optimization. The cultural dimensions cover the attitudes and the readiness to base decisions and operations on data insights. Lastly, Management covers the governance and strategies for handling and using the data as a whole in the organization (Becker, Knackstedt and Pöppelbuß, 2009; Cosic, Shanks and Maynard, 2012; Parra *et al.*, 2019).
To provide a common categorization of the different maturity levels from the models presented in the literature, three categories have been developed: Low, Medium and High. The categories have been derived from the presented maturity models based on the levels. Despite the variation in definition and number of levels in the models, there seem to be a similarity between different stages of the models, which is natural as the models in some level follows an evolutionary progress (Becker, Knackstedt and Pöppelbuß, 2009) (see Table 3-3).

Table 3-3 - Levels of data maturity

Level	*Comuzzi & Patel (2016)*	*Parra et al. (2019)*	*Becker et al. (2009)*	*Cosic et al. (2012)*	*Król & Zdonek (2020)*	*Results*
0	Lack of awareness		Non-existent	Non-existent		Low / Initial
1	Individual driven	Uninitiated	Initial	Initial	Initiation	
2	Developing	Awareness	Repeatable	Intermediate	Infection	Medium / Established
3	Managed	Proactive adopting	De-fined	Advanced	Acceleration	
4	Advanced	Integral embracement	Managed	Optimized	Momentum, Impulse	High / Advanced
5	Innovative	Completely Embedded	Optimized		Ahead, On the front	

To develop the operational definition and to be able to assign organizations to the categories, the categories has been used to assess and define the dimensions derived.

The **Low / Initial** category represents no or only initial use of data. Despite multiple authors separating this into two categories, i.e. non-existent and initial (Becker, Knackstedt and Pöppelbuß, 2009; Cosic, Shanks and Maynard, 2012; Comuzzi and Patel, 2016), the two categories has been comprised into one for the sake of simplicity of the model. The assets are generally older and may need to be supervised manually with visual inspections to determine the performance. There is very little or no possibilities for extracting data from the machinery and/or the company has poor infrastructure to facilitate dataflow. There are little to no skills connected to the organization, internal or external, that are capable to collect and analyze the data and transform it into operational information. Additionally, there is no or only initial governance and strategy elements under development for data-driven asset management.

The **Medium / Established** category represents some form of data regularly used in asset management processes. This is comprised of several categories from the literature. Common for these are that there is some kind of progression in the process of utilizing data for AM, and that there some level of organizational awareness and development of processes in place. The assets have some kind of mechanisms built in or retrofitted that makes it possible to extract asset data through industry standard interfaces or connections and/or there is a some analytic/technical capabilities connected to the company that is able to exploit the collected data. Furthermore, data-driven asset management has been accepted and formalized by management, which has established some governance and strategy for data-driven asset management.

In the **High / Advanced** category, data is used on an advanced level. Here, advanced algorithms are developed to predict specific components life cycle or root causes of failures. The use of data is completely embedded in AM processes, where it is used efficiently and innovatively to stay ahead. Assets are highly advanced and digitally connected and are able to provide instant high-quality information about its condition. The IT infrastructure is optimized to facilitate constant dataflow. The organization possesses highly specialized data analytic capabilities able to develop and maintain advanced algorithms to ensure optimal condition of assets. Moreover, advanced data-driven asset management is a key element in the organizations strategy and governance and structures has been optimized to ensure future advancement and innovation within data-driven asset management.

3.1.4.2 Maintenance strategy dimension

With the baseline categorization for the data maturity part of the model mapped, the next step is to ascertain the categories needed for the maintenance strategies that should be a part of the model as well. This categorization is roughly based on the terminology from CEN 13306:2017. However, to better ascertain and create a comparison between data maturity and maintenance strategy, the maintenance categories needs to be compiled in a different manner. Specifically, regarding the usage of corrective and preventive maintenance. The need for a different approach to the categorization stems from the setup of the data maturity model, that have a three-dimensional approach to determining the data maturity of an organization.

Hence, the maintenance strategies should reflect that setup, so that the comparison of the maintenance strategies and data maturity dimensions are possible. Therefore, in relation to the corrective maintenance category, that is going to be represented as an ad hoc maintenance strategy. This is based on the data collected through the case studies.

Preventive maintenance is in juxtaposition to the corrective maintenance approach, which allows for potentially fewer failures and a better overview of the oncoming failures and needs for repairs. However, with preventive maintenance being an umbrella term for condition-based maintenance and predetermined maintenance, each are going to represent a maintenance dimension in the comparative matrix. The predetermined maintenance strategy represents what is categorized as the second dimension in the maintenance strategy. Whereas ad hoc maintenance strategy represents level one. The reasoning for the placement of predetermined maintenance in contrast to ad hoc based maintenance is that an ad hoc based maintenance strategy generally is considered less costly and process heavy. Predetermined maintenance on the other hand is implemented if downtime is more critical to the production flow. Predetermined maintenance primarily comes as scheduled maintenance based on operational time or produced metrics.

The third dimension is condition-based maintenance strategy. This strategy is presented as the last level because of the wide reach that a condition-based approach can accomplish if sufficiently implemented in collaboration with a high data maturity. However, it can also represent an output of primarily experienced based maintenance activities that are completed based on subjective understandings of the production equipment, which have been established through extensive employment in the field of maintenance. With the extensive field of maintenance that are possible within the strategy of condition-based maintenance, the approach chosen is highly dependent upon the capabilities of the organization and the data maturity present in the respective organization. However, based on the possibilities that are available within a condition-based maintenance strategy it is placed as the third dimension. Meaning that is employed in a highly efficient and data driven organization, it may be possible to achieve a predictive maintenance setup, see summary in table 3-4.

Table 3-4 - Dimensions of maintenance strategy explained

Maintenance strategies	*Description*
Ad hoc	Run to failure like, only completing maintenance when necessary or if government mandated.
Predetermined	Scheduled maintenance, that can be based on time, production output etc.
Condition-based	Has an extensive span, from conducting maintenance based on employee experience to predictive maintenance based primarily on data collected in the production fed to intelligent algorithms that plans the maintenance activities.

3.1.4.3 Comparative matrix development

To systematically assess the relationship between data maturity and maintenance strategy, a comparative matrix was developed by synthesizing insights from literature and empirical case studies. The rationale behind this model is to provide a structured framework for evaluating an organization's maintenance approach in relation to its data capabilities. The matrix categorizes maintenance strategies and data maturity into three distinct levels, allowing for a comparative analysis that highlights areas of alignment and potential for optimization.

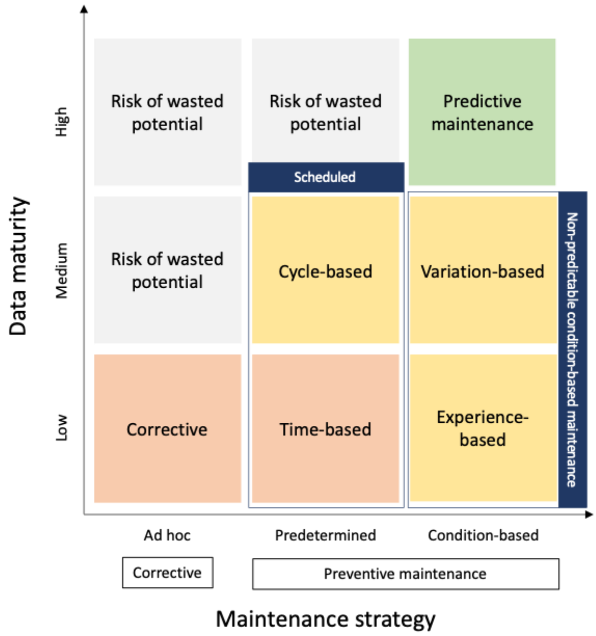

Figure 3-2 - Comparative matrix of maintenance strategy and data maturity

Figure 3.2 was constructed based on established maintenance theory and data maturity models, adapted to fit the SME context. By integrating theoretical foundations with real-world observations from case companies, the model enables organizations to diagnose their current state, identify gaps, and inform strategic decision-making for improving maintenance efficiency and Industry 4.0 adoption. The proposed model illustrates the newly proposed categories in a 3x3 matrix according to their relations to the general complexity of maintenance strategies and data maturity.

The categorization is developed from existing literature and the empirical data from the case studies. The model will be used to map the interviewed companies on a general business level, indicating the direction of the company's strategy.

The **Corrective** category represents a corrective maintenance strategy, where components are not repaired or replaced before errors have been detected. According to the CEN 13306 corrective maintenance is divided into "immediate"- and "Deferred Corrective Maintenance" but is merged in this model, as the neither is more sophisticated than the other in terms of strategy nor data maturity. This approach was found in Company B where the general strategy was to run equipment until failure.

The **Time-based** and **Cycle-based** category represents a preventive maintenance strategy with predetermined maintenance. In Time-based, maintenance is planned based on time passed since last, where Cycle-based is planned based on actual activity of the asset. This difference was highlighted as very significant by Company A. Therefore, it was decided to split the "Scheduled maintenance" into two separates instead.

The **Experience-based** and **Variation-based** categories both represent a preventive maintenance strategy, where maintenance is scheduled based on the condition of the asset. The categories are created from splitting the "non-predictable condition-based maintenance" category from ISO 31000 into two. The reason behind this can be found in the data from Company D, where a high degree of maintenance was carried out based on experience from the service technician. This differs from the previous categorization of "Time-based" maintenance, which is again predetermined, comparatively to an **experience-based** approach which is largely intuition-driven. Opposite, the **Variation-based** category represents a more data-driven approach as seen in Six Sigma literature, where statistical data is analyzed to determine variation in processes and thereby determine the condition of the equipment. As this data-driven approach requires higher data maturity, this category is higher placed than "Experience-based".

Lastly, the **Predictive Maintenance** category represents a preventive, condition-based maintenance strategy, where upcoming errors are detected before they occur based on the condition of the machine and complex algorithms. The remaining boxes on the model represent a risk of wasted potential. If assets are supported by high quality data and capabilities but still are submitted to a corrective maintenance strategy, the maintenance processes could be optimized. However, in the case of Company B, there was an overcapacity in production, making it possible to plan around breakdowns. As there are no significant consequences of failure, this might provide a weak business case of developing algorithms to predict failures. Yet, in many cases wasted potential would be wasted production hours or wasted output because of asset breakdowns, which is directly assimilated with costs (Dahlgaard and Dahlgaard-Park, 2006), why this is adopted for this model as well.

3.1.4.4 Exemplification of model

To further exemplify the proposed matrix, the four case companies were positioned within based on the empirical findings from the interviews conducted. Their placement reflects the degree of data maturity and the maintenance strategy each company employs. The evaluation considers factors such as the extent of data collection, storage, and utilization, as well as the structure and predictability of their maintenance practices. The placement of Companies A to D in Figure 3.3 is based on the interview data presented in 3.1.3, analysed against the defined data maturity and maintenance strategy dimensions as detailed in 3.1.4. The placements were not validated with the companies post-analysis.

Company A was positioned in the medium data maturity and cycle-based maintenance category. While the company does not actively collect and analyze extensive data, it does employ basic mechanical counters on its molds and uses experience-based visual inspections. Their maintenance strategy is semi-regular and follows runtime or fixed intervals, aligning with a cycle-based predetermined maintenance approach. The potential for enhanced data utilization exists, yet it remains largely untapped, placing Company A in the risk of wasted potential zone.

Company B was categorized in the low data maturity and corrective maintenance quadrant. The company does not systematically collect or utilize production data, nor does it integrate data-driven decision-making into its maintenance strategy. Instead, it employs a run-to-failure approach, meaning maintenance is only performed when breakdowns occur or when legally mandated. Given the absence of a structured maintenance strategy and limited data capabilities, Company B is classified under the corrective maintenance category with low data maturity.

Company C was placed in the medium data maturity category with a maintenance strategy that exhibits characteristics of both condition-based and predetermined maintenance. The company has implemented data collection mechanisms and utilizes data for operational insights, including Overall Equipment Effectiveness calculations. However, despite having these capabilities, its maintenance approach does not fully capitalize on data analytics, creating a risk of wasted potential. This places Company C in a transitional state where improvements in data integration could significantly enhance its predictive maintenance potential.

Company D was positioned in the low data maturity and experience-based maintenance category. While the company acknowledges the need for a more structured maintenance approach, its current strategy is largely based on intuitive decision-making and operator experience. There is no formal data collection process in place, and maintenance tasks are performed in a reactionary manner based on perceived need rather than systematic scheduling. This reliance on informal, experience-driven maintenance aligns with the low data maturity, condition-based maintenance quadrant.

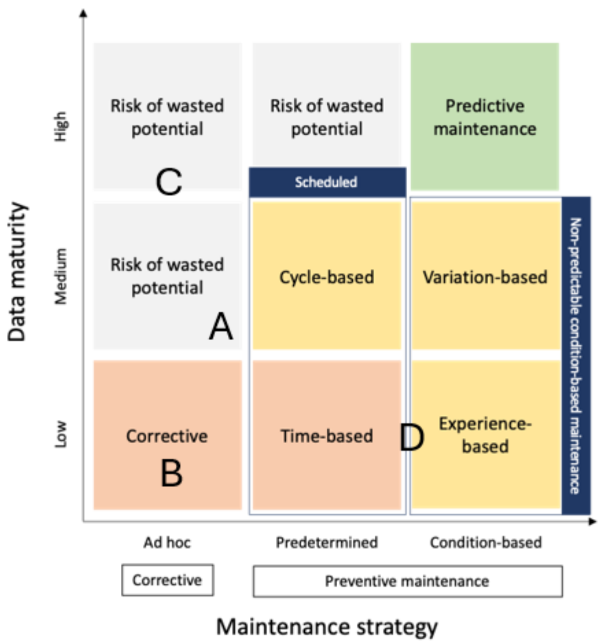

Figure 3-3 - Proposed data maturity and maintenance matrix with case company placements

The placement of these case companies in the matrix in figure 3-3 highlights the diverse approaches to maintenance and data utilization within SMEs. Companies with higher data maturity but inadequate maintenance structures (e.g., Company C) exhibit wasted potential, while those with low data maturity and reactive maintenance strategies (e.g., Company B) face increased operational risks. This model serves as a diagnostic tool for assessing organizational readiness and guiding decision-making towards optimized maintenance strategies and enhanced data utilization in Industry 4.0 environments.

3.1.5 Discussion and conclusion

This paper highlights the relationship between data maturity and maintenance strategy. Especially data maturity understood as the ability of the enterprise to plan, collect, process, enrich, decide and operate from IoT-inspired sensor networks. Here consult table 3-2 and figure 3-2 to establish current and desired data maturity level. Also figure 3-1 serves to navigate current and potential maintenance approaches, e.g. predictive maintenance cannot supersede schedule maintenance if this is to assure compliance. The framework stipulated should offer a key take-away to decision making on adjusting the needs for operational performance and operational asset management efficiency and data. Industry 4.0 constitutes a technology-driven momentum on sensor networks and IoT. Continuous improvement regimes suggest OEE as a key parameter. But especially SMEs have to assure resources are spend wisely and accordance with business strategy and fundamental needs of the operational planning. The framework of this paper can thus posit in the balance between enterprise capabilities and technological opportunities in the development IoT sensor networks for condition monitoring.

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3.2 The Exploration of Digitalization and Digitalization Indicators Within the Scope of Asset Management

The following extended conference paper partly answers RQ2.

Brasen, L.P.H., Tambo, T. (2023). The Exploration of Digitalization and Digitalization Indicators Within the Scope of Asset Management. In: Crespo Márquez, A., Gómez Fernández, J.F., González-Prida Díaz, V., Amadi-Echendu, J. (eds) 16th WCEAM Proceedings. WCEAM 2022. Lecture Notes in Mechanical Engineering. Springer, Cham. https://doi.org/10.1007/978-3-031-25448-2_30

The published version of this paper can be found on this link:
https://link.springer.com/chapter/10.1007/978-3-031-25448-2_30

The content of this subchapter is directly copied from the paper, with minor changes for formatting.

Abstract: Asset management has in the last two decades been introduced and become a larger part of academic discussions. Considering the rising complexity regarding the operation of a company, asset management enables some alleviation of that. Digitalization is likewise a newer terminology that has become part of the operational language in the industry, but the interlink between AM and digitalization is not necessarily clear-cut. This paper seeks to examine that interlink and on behalf of a questionnaire conducted on practicing professionals investigate the overall maturity level of their efforts in explicit digital application, implicit digital application, and within areas where no digital application exists. Thus, showing gaps in the relation to the practicing professionals' understanding and application of digitalization within the scope of asset management.

Keywords: *Digitalization, Asset management, Maturity assessment, Engineering asset management*

3.2.1 Introduction

Complexity and problems derived from complexity have long been a focal point in the academic discussion on Asset Management (Liyanage, 2017a). The increase in complexity is a product of several different emerging circumstances that affect production environments, ranging from internal circumstances such as aging physical assets to integration of knowledge-intensive new technology. This correlates with an increase in diverse commercial, political, socio-economic, and ICT-related uncertainties in the current industrial ecosystem. Externally, circumstances such as a rapidly changing environment and continually evolving customer requirements are likewise a contributor (Liyanage, 2017b). However, with complexity and risk, opportunities also arise. New emerging technologies that enable better planning, maintenance, tracking of assets and overall asset management are prevalent, if organizations know where to look and are willing to invest and embrace some risks. However, embarking on a digitalization journey is of course not as simple as retrofitting a sensor or two on old manufacturing equipment, and thus, capabilities and maturity of the systems, processes and employees need to be considered, among others. Considering that, a digitalization journey is a substantial and risk-heavy undertaking especially if performed by ill experienced individuals on less than mature equipment and processes pertaining to that equipment, serious considerations are required. However, the benefits of digitalization do have a proven track record of increasing competitiveness if introduced intelligently and strategically (Algabroun *et al.*, 2022), but the company has to be sufficiently mature to orchestrate such massive changes.

Digitalization is a major contributor to this complexity rise, but also an answer for better decision-making and efficiency improvements. Digitalization at its core is about the increased use of digital technologies and the integration across a company's products and internal and external activities (Björkdahl, 2020). Hence, the ability for digitalization to affect, create and capture value for a company, as fundamental changes to their operation are made. Digitalization can in simple terms be seen as an increase in the capabilities for data generation, analysis and data use, to improve decision-making. Thus, improving internal efficiency and likewise introducing more value for the customer through changes from ana-log to digital formats (Björkdahl, 2020).

Furthermore, with Asset Management being a relatively new concept within the operational perspective of the organization, only been significantly focused on in the last two decades in the context of operational management (Mathew *et al.*, 2006), the interlink between digitalization and Asset Management is an interesting area of research. Especially, when considering that Asset Management arguably exists under the same umbrella that digitalization exists under. Specifically, correlated with the understanding that a solid foundational understanding of the operation is needed along with a maturity that allows organizational changes to hap-pen. The prevalent definition of Asset Management is sourced from the industry standard, specifically; the act of translating the organization's objectives into decisions, plans, and activities that are asset-related using a risk-based approach (ISO 55000 series, 2014).

Recognizing that both asset management and digitalization can provide measures or solutions that alleviate complexity, the two concepts can just as easily create complexity. Hence, the need for an exploratory investigation into indicators and interlinks between the two concepts of asset management and digitalization. Especially, considering the current industrial climate and the daily struggles that practitioners may suffer under, alleviating or at least providing suggestions for alleviating measures are valuable. Thus, this paper explores the role of digitalization within the scope of Asset Management and examines how digitalization initiatives can help address the complexities associated with managing physical assets. By analyzing industry trends and self-assessed digital maturity levels, the study aims to identify key indicators that reflect the current state of digital adoption and highlight potential areas for improvement. These indicators are not intended as rigid, numerical benchmarks but rather as guiding signals that can assist asset managers in planning and strategizing future digitalization initiatives. Specifically, they help identify disparities in digital maturity across industries, gaps between explicit and implicit digitalization, barriers to implementation, and opportunities for foundational improvements. By recognizing these patterns and trends, asset managers can make more informed decisions on how to prioritize digital transformation efforts, ensuring that initiatives are both strategic and operationally beneficial.

3.2.2 Methodological considerations

The paper investigates digitalization within the scope of asset management from two directions. First off, an exploration of relevant literature is conducted. The narrative literature review sets out to establish a foundation for the use of digitalization within engineering asset management, and asset management.

The second approach triangulates findings from the literature with data from a questionnaire conducted among 66 industry professionals within the Danish Industry. The questionnaire explores various aspects of the asset management process, including statements related to maintenance strategies and the organization's ability to track asset data within management and planning software. It employs a Likert-scale format, where respondents rate their agreement with each statement on a scale from 1 to 5. A response of 5 indicates full understanding and application, while a response of 1 signifies a lack of understanding or an inability to implement the given practice. Intermediate values (2–4) represent varying degrees of understanding and application, with 3 indicating an average level of maturity in relation to the statement. For the purposes of this study, a score of 5 is considered indicative of full maturity in the given area, while a score of 1 reflects minimal or no maturity.

The dataset used in this study was provided by an industry organization specializing in maintenance and asset management. This organization has a membership base of several hundred companies, who constituted the primary respondents to the survey. The questionnaire, conducted via an online survey platform, consisted of 128 carefully designed questions aimed at assessing respondents' perceptions of their organization's maturity in asset management and maintenance practices. The sample, while limited to 66 professionals, offers valuable insights into industry-wide deliberations on key asset management challenges. This dataset is particularly relevant to this research as it directly addresses themes of asset management, digitalization, and maintenance. Furthermore, the comprehensiveness of the questionnaire, covering multiple disciplines within asset management, strengthens its applicability to the study. Given the challenges associated with conducting a large-scale industry survey independently, leveraging this dataset from a well-established industry organization provides a robust and practical alternative. Additionally, the credibility of the data is reinforced by its alignment with established industry practices and the expertise of the professionals who contributed their insights.

As this specific paper focuses on the digitalization aspect of the questionnaire a sorting of the 128 questions was a necessity, with the questionnaire specifically catering to broader asset management and maintenance perspective, rather than specifically digitalization. Therefore, three categories were constructed; *explicit, implicit*, and *no system or IT influence or connection*.

Table 3-5, shows the distribution of categories. An example of an explicit question could be, *whether mobile solutions are used to enable on-site reporting*. Meaning a question stating explicitly an application of systematization or digitalization applied in the company. Whereas, an implicit question could be, that there exist job descriptions for preventive tasks. This in contrast to the explicit category relates to the implicit application of digitalization efforts or systematization. Thus, the example mentions *that job descriptions exist for preventive tasks*, hence, the storage of said job descriptions is implicitly linked to a system, which arguably is digital.

Lastly, the final category could be; *All work orders are prioritized objectively or after given rules*. The final category is specifically related to questions where no explicit or implicit application of digitalization or systematization occurs.

Table 3-5 - Sorted categories of the questionnaire

Explicit	Implicit	No System/IT	Total
36	39	53	128

Another critical aspect of the questionnaire that requires consideration is the categorization of respondents based on their respective industrial fields. This classification was deliberately designed to ensure a meaningful analysis of indicators toward digitalization within distinct industry contexts. The dataset has been structured into three overarching industry categories: *manufacturing, logistics & infrastructure,* and *maintenance services*. The distribution of respondents across these categories is presented in Table 3-6.

Table 3-6 - Categories of respondents

Manufacturing	Logistics and infrastructure	Maintenance services	Total respondents
29	28	9	66

The choice of these three categories was made to strike a balance between industry specificity and analytical clarity. Given the relatively small dataset, further broadening the scope would risk diluting the results, making it more difficult to draw clear conclusions. At the same time, the chosen categories represent three fundamentally different yet interconnected industry perspectives on asset management and digitalization, ensuring that the analysis captures meaningful variations in maturity levels.

Manufacturing represents organizations that primarily focus on producing goods through their assets. Digitalization in this context revolves around optimizing production efficiency, predictive maintenance, and automation to enhance throughput and minimize downtime.

Logistics & Infrastructure includes organizations where assets are not primarily for production but are instead critical to enabling services, whether in transportation, supply chain operations, or infrastructure management. In this category, asset longevity, tracking, and operational reliability are central concerns, as failures directly impact service delivery.

Maintenance Services consists of organizations that provide maintenance solutions for assets owned by others. These companies ensure that manufacturing and logistics organizations can sustain high performance and reliability through specialized maintenance expertise, predictive analytics, and service innovations.

By structuring the analysis within these three categories, the study ensures a focused yet comprehensive approach to understanding digitalization maturity across different industry roles. This categorization allows for meaningful comparisons and insights without overcomplicating the analysis or reducing its validity due to an overly fragmented dataset.

3.2.3 Theoretical position

3.2.3.1 Engineering asset management

Engineering asset management (EAM) is a term and a concept related to the management of assets engineered specifically to perform a given task, which in most cases refers to physical assets operated by an organization. Considering that asset management is referring to the coordinated activities of an organization to realize value from an asset (ISO 55000 series, 2014), engineering asset management is the natural extension of that. Trying to realize value from physical engineered assets that perform a given task in an operation (Amadi-echendu *et al.*, 2010).

Likewise, whereas an asset is an all-encompassing terminology relating to an item, thing, or entity that has potential or actual value for an organization (ISO 55000 series, 2014), the engineering asset refers to things, items or entities engineered to create as much value for the organization as possible. Hence, the engineering as-set correlates to the foundational parts of an operation, without which other asset types (financial e.g.) won't be achievable (Amadi-echendu *et al.*, 2010).

With EAM the enterprise must establish an informed position on its focal masse of assets. The ISO 55001 (DS/ISO, 2014) standard defines the need for the registration of assets in the key aspects of identification, value, life-cycle, data of operations, and maintenance (Congalton and Gatland, 2019). Secondary aspects can be added in aspects such as vendor, maintenance relations, time series, and decommissioning. Managed assets are critical to constituting valid configurations of the combined operational fabric of the enterprise (Pakkanen, Juuti and Lehtonen, 2020). No matter if, we talk about locomotives, dairy plants, public utilities, food production, data centres, etc. The informed position on assets further must ensure responsible value preservation throughout the asset's lifetime with activities such as service, replacement, and upgrades (Rampini *et al.*, 2020).

3.2.3.2 Digital transformation

The megatrend of Industry 4.0 expressed digitalization as central to industrial development and transformation (Roberts *et al.*, 2018). In general, enterprises are investing substantially in digital transformations where more analog business models are phased out to make space for digitalization throughout business processes, supply chains, and services. This digital transformation significantly influences multiple sectors within manufacturing, ranging from food production to machining. Variability in the investments and applicability of the digitalization measures exist, and thus no clear direction for how to go about it is uniformly applicable. However, certain investments into sensors and equipment that improves decision-making have showcased markedly better results than not investing in these technologies. This is either through retrofitting old equipment with new tools for enabling better decisions or conducting investments into new production equipment overall (Al-Maeeni *et al.*, 2020). Observations of digitalization efforts in the manufacturing industry show that the effects of digitalization primarily are traced to creating more efficient firm operations and manufacturing processes. In addition to, improving the performance of products supplied to a customer typically through new functionalities (Björkdahl, 2020). This largely translates to improved production throughput, fewer breakdowns, as maintenance activities can be planned and structured better, and an increase in integration across activities in the internal value chain, which does provide cost advantages (Buer *et al.*, 2021). However, these initiatives towards efficiency improvements to the internal operations and value chain do introduce new procedures and activities that could complicate operations, if there is a lack in understanding of the current foundational operations. Some argue that Lean is a prerequisite for digitalization in manufacturing (Klötzer and Pflaum, 2017), whereas EAM also could provide a foundational understanding and synergy with digitalization (Cho, May and Kiritsis, 2020).

3.2.3.3 Digitalization of EAM

Asset Management (AM) is inherently a data-intensive discipline, relying on continuous asset information to facilitate decision-making and ensure effective integration into broader operational systems (Chang *et al.*, 2022). With the rise of Industry 4.0, Engineering Asset Management and operational technologies must increasingly be viewed through the lens of digitalization (Algabroun *et al.*, 2022). A substantial proportion of assets now exist as digital entities, making their integration into digitally operated systems a fundamental requirement for modern industrial practices (Teoh, Gill and Parlikad, 2023). To maximize asset efficiency, digital representation on operational platforms is crucial for key functions such as capacity planning, service management, spare parts inventory, warranty tracking, and economic equity. The increasing adoption of predictive maintenance and analytics further underscores the need for digitalization, as engineering assets must be fully digitized to support these advancements (Cho, May and Kiritsis, 2020).

Despite the benefits digitalization offers, several barriers hinder its full implementation. Ahonen et al. (2019) highlight challenges such as insufficient technological readiness, the absence of innovative business models, a lack of appropriate tools, and high implementation costs. Furthermore, while the decreasing costs and increasing availability of sensors, monitoring technologies, and tracking systems have made digital transformation more feasible, organizations must still manage the complexity of implementation and integration (Cho, May and Kiritsis, 2020). Applying digitalization measures within the EAM framework enables companies to enhance their insights into production, maintenance, and overall operations through improved data availability (Roberts *et al.*, 2018). However, the process of digitalizing engineering assets is expensive, complex, and comprehensive, necessitating strategic planning and structured decision-making before organizations can fully realize its benefits.

3.2.4 Analysis

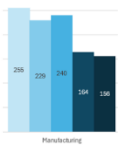
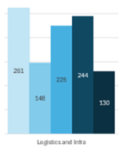
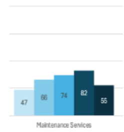
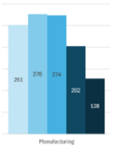
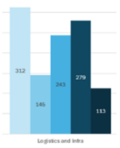
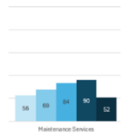
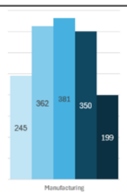
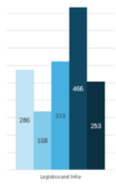
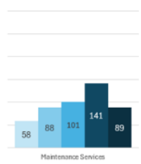
Considering the argument that asset management and digitalization are synergistic, the intrinsic value of understanding the maturity of the different industrial categories is considerable. Identifying the industrial category with the most mature digitalization efforts not only provides insights into industry-specific advancements but also enables a more detailed analysis of key trends. Additionally, highlighting areas where overall digital maturity is lower can offer valuable guidance on potential areas for improvement. While this does not prescribe specific actions, it helps identify key indicators that signal where digitalization efforts could be enhanced or further explored.

The questionnaire survey provides critical insights into the extent of digitalization adoption across three distinct industries related to AM, as the respondents primarily consist of AM practitioners and maintenance managers. While digitalization is widely recognized as a key industrial agenda (Roberts *et al.*, 2018), its measurable perceived maturity level, particularly within AM, remains insufficiently explored. By incorporating 128 statements addressing various aspects of AM and maintenance, the survey responses facilitate a maturity assessment of the Danish industry. This assessment helps identify specific areas where digitalization initiatives can be effectively implemented, as well as instances where digital adoption may be less beneficial or unnecessary, thereby supporting strategic decision-making in digital transformation efforts.

Considering that, the interlink of digitalization or at least systematization and asset management is supported by the current industry standard which makes it clear that systematization is a necessity for conducting asset management (ISO 55000 series, 2014). Systematization varies across companies, often influenced by organizational needs and technological capabilities. In most cases, it is driven by IT tools, ranging from basic spreadsheet applications such as Excel to more sophisticated Enterprise Resource Planning or Enterprise Asset Management systems. Further, systematization within organizations refers to the process of organizing and standardizing procedures to enhance efficiency and effectiveness. This concept encompasses the development and implementation of systematic methods to manage organizational activities, i.e. Asset management is a systematic approach that can be embraced. However, advancing beyond basic systematization into full-scale digitalization requires the integration of more complex technologies. Tools such as sensors, machine learning, artificial intelligence, the Internet of Things, and digital twins present significant opportunities for optimizing operations and predictive maintenance. Despite their potential, these advanced digitalization tools pose substantial challenges. Implementing such technologies in-house is often complex and resource-intensive, while procuring them externally can be prohibitively expensive. Additionally, retrofitting existing assets with new digital components involves considerable investments in time and potential disruptions to production.

The trade-off between cost, complexity, and operational continuity is therefore a critical factor in companies' digital transformation strategies. Table 3-6 shows the overarching results on the 1 to 5 scale for each specific category of industry in correlation to the category of questions related to digitalization. Concerning table 3-6 and the information within, the data is a median of 128 questions and 66 respondents. When analysing individual responses, some participants exhibit a higher self-perceived understanding of the questionnaire topics. However, since this study focuses on industry-wide trends rather than individual assessments, the results are evaluated at an aggregate level. The median values presented in Table 3-7 provide a representative measure of overall industry maturity, ensuring that the findings reflect broader sectoral patterns rather than outlier perceptions. Due to confidentiality agreements with the industry partner, the questionnaire cannot be included as an appendix. However, the questions were categorized into explicit, implicit, and no-system/IT on their relation to digitalization (see Table 3-5). The topics span preventive maintenance, system support, data handling, resource strategy, condition monitoring, failure analysis, and collaboration across maintenance, production, and suppliers. This classification reflects varying degrees of digital/system influence within asset management practices.

Table 3-7 - Correlation between industry and question category to indicate overall understanding and maturity level

Question Categories	**Respondent category**	**Manufacturing**	**Logistics and Infrastructure**	**Maintenance Services**
Explicit		2,75 	2,84 	3,10 
Implicit		2,72 	2,76 	3,04 
No System/IT		2,93 	3,16 	3,24 

3.2.4.1 Manufacturing Lags Behind in Digitalization

The Manufacturing industry consistently reports self-assessed maturity scores below the threshold of 3 across all three categories. According to the maturity scale defined in Section 3.2.2, this suggests that manufacturing companies perceive themselves as less advanced in both understanding and application of digitalization in Asset management and maintenance management.

This disparity indicates a clear potential for improvement, highlighting the need for targeted initiatives to enhance digital maturity within the Manufacturing sector. In contrast, Logistics & Infrastructure and Maintenance Services demonstrate higher perceived maturity levels, positioning them ahead in the adoption and integration of digital asset management practices.

3.2.4.2 Trends in Digitalization Across Industry Categories

Even though Manufacturing lags, the differences between the industry categories are relatively small, with the largest gap being 0,40 points between the Implicit and No System/IT categories for Logistics and Infrastructure. This suggests that while Manufacturing is behind, the overall spread of digitalization maturity is not extreme across industries.

The No System/IT category consistently received higher maturity scores across all industries compared to Explicit and Implicit digitalization. This suggests that companies feel more confident in their traditional asset management practices but are less mature in structured digital applications. This also highlights a potential transition challenge, where firms must move from well-established non-digital processes to structured digital asset management solutions.

3.2.4.3 Lack of Complete Digitalization Readiness

Surprisingly, none of the industries scored above 3.24 in any category, with Maintenance Services scoring the highest. This suggests that no industry perceives itself as having fully mastered digitalization within AM. The median maturity scores hovering around 3 indicate that most companies fall into an "average" understanding and application level, rather than showing a strong digital transformation. Given that Industry 4.0 and digital transformation initiatives have been actively promoted for over a decade, these results indicate that many companies may still be cautious or slow in adopting digital tools for asset management.

3.2.4.4 Survey findings linked to category characteristic

Furthermore, the characteristics of the three different categories of industry are probable sources of the differing results in the survey findings. I.e. Manufacturing companies often operate older legacy systems, leading to slower digital adoption and a reliance on manual asset management practices. Their lower scores in Explicit digitalization indicate that they have yet to fully integrate IT tools and digital workflows into AM and maintenance operations.

Whereas Logistics & Infrastructure companies require real-time tracking, monitoring, and automation for supply chain efficiency, which may explain their higher digital maturity scores. The relatively small gap between their No System/IT and Explicit scores suggests a stronger push for digital adoption in their operational structure.

And finally, Maintenance Service providers derive benefit from predictive maintenance, condition monitoring, and service automation, explaining why they lead in digital maturity. Their need for advanced maintenance technologies likely drives their higher scores in Explicit and Implicit digitalization.

The questionnaire is giving an interesting view into the mindset of AM practitioners in the sense of critical positions to digitalization reflected in the hesitant or sceptic answering values. The spread of the values indicates that the respondents are sincere in their answers, based on careful evaluations and experience.

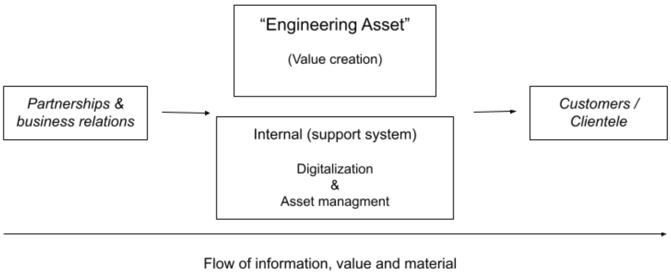


Figure 3-4 - Contextualization of the engineering assets role within a simple industrial eco-system

Figure 3-4 is a simple, albeit, important overview of the placement of the engineering asset in relation to the flow of information, value and materials in the value stream. It is inspired by the work done in Brasen and Liyanage (2022), and encapsulates the role of the asset in the ecosystem within which it operates. From suppliers and business partner's, information and material, is input into the asset, which in turn are supported by the internal activities, processes and technologies of digitalization and asset management, to create as much value as possible. This value, typically a physical product within manufacturing, is when shipped to a customer or clientele on the right. This contextualization of the role of the engineering asset in relation to digitalization and asset management is important, as it displays the application of these two activities as a means of supporting the generation of value that the asset produces, thus maximizing the value of the asset in turn. Hence, the argumentation that heightening the maturity in relation to both conducting asset management, but certainly also related to digitalization could improve this value creation further.

With the understanding from the data that there is potential improvement in all categories of questions across all industries, the question is then what specifically the respondents in the questionnaire, as well as others industry professionals can do. Figure 3-5 is an approximation of pro's and con's related to AM and digitalization, and that two-way configuration on the negatives and positives allows for deeper insights into how to approach the creation of indicators for digitalization and the development thereof. The model is an aggregate of the findings from the narrative literature review.

Pros and Cons - Digitalization within EAM

Pros	Cons
More data Better decisions Efficient monitoring Higher up-time	Driver of cost Driver of complexity Lack of qualified resources Industry 3.0 or 4.0

Figure 3-5 - Pros and Cons related to digitalization within EAM

On the positive "Pro" side of figure 3-5, benefits related to digitalization are presented. More data of course is not necessarily a benefit, however when introduced intelligently and within the framework and foundation of an organization that knows what to do with the data, it is a valuable tool for especially better decisions. Efficient monitoring and Higher up-time are likewise possible benefits than can be achieved by the introduction of digital monitoring and sensors among others, and arguably also a product of more and "better" data.

In view of the data presented and the insights from the literature, as well as data gathered from industry, several key indicators related to digitalization within the scope of AM can be identified. These indicators help highlight areas for improvement and provide guidance on strategic implementation.

Digitalization Maturity Disparities: The data reveals that manufacturing lags in digitalization maturity compared to logistics & infrastructure and maintenance services. This suggests that industry-specific challenges influence digital transformation differently across sectors. Understanding these differences is critical for identifying where digitalization investments should be prioritized.

Explicit vs. Implicit Digitalization Gaps: The findings indicate that explicit digitalization efforts (e.g., IT systems, digital workflows) are generally less developed than implicit digitalization (e.g., standardized procedures, structured processes). This gap suggests that while companies may have established work structures, they lack formalized digital tools and systematization. Addressing this disparity through targeted digital adoption strategies is an essential step toward improving overall digital maturity.

Opportunities for Foundational Improvements: The no system/IT category demonstrates higher maturity scores than explicit and implicit digitalization, indicating that many companies have strong foundational asset management practices but have yet to fully integrate digital solutions. This aligns with the argument that organizations should focus on strengthening foundational activities before introducing complexity through new digital technologies. Ensuring operational stability and maturity before pursuing digital transformation is essential for long-term success.

Barriers to Digitalization: The study reinforces barriers identified by Ahonen et al. (2019), including technological readiness, cost, lack of digital tools, and insufficient business models. These challenges act as key indicators of resistance to digitalization and highlight the importance of strategic planning, resource allocation, and training initiatives to facilitate digital adoption. Identifying the specific inhibitors and drivers, such as cost, complexity, value creation, and skill availability, within an organization is critical for ensuring a structured and effective digital transition.

Strategic Considerations for Digitalization: As value creation in engineering assets is fundamental, all supporting functions, including digitalization, must be aligned with this objective. Digitalization should enhance value creation rather than become an isolated initiative. Hence, organizations should focus on optimizing value generation through AM before digitalizing processes unnecessarily.

By integrating these indicators into asset management strategies, companies can better navigate digital transformation efforts, ensuring that initiatives are contextually relevant, strategically beneficial, and aligned with overall business objectives.

3.2.5 Conclusion

Based on the results of the questionnaire and the brief literature overview, digitalization has become a clear part of the maintenance and asset management efforts. Digitalizing data and processes have allowed for an integration of systems and processes, which does provide a clear benefit if integrated correctly. However, the indication is that in large part the respondents on the questionnaire are lacking in their overall efforts towards digitalization and asset management integration. Thus, a greater focus should arguably be on the fundamentals, with the no system/IT part category, in large part being these companies' license to operate.

With that understanding and that, the paradigm of Industry 4.0 and digitalization is influencing and driving the economy, and that Denmark is a leading driver of a digital economy, the data on contrast shows that, that is not the case in the responses among the industry professionals. Hence, there seems to be either natural skepticism or other influencers on why that is.

An important distinction regarding the data set and analyzing the data as a whole rather than single responses is that it does provide a bleaker picture of the industries. However, first-movers and best-in-class examples do exist, at least based on their self-perception of the questions in the questionnaire, but likewise, respond-ents that do not perform that well also exist. Hence, the largest average results. However, with industry 4.0 initiatives having been published in 2013 (Björkdahl, 2020), and the launch of the asset management standard in 2014 (ISO 55000 series, 2014), almost 10 years have passed, and an argument can be made that companies should be more mature considering these factors. This is not the case when considering the data presented in this paper, at least from a maturity perspective.

3.2.6 References

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4 Chapter 4. – Agile and Asset Management

This chapter consists of a single publication, Agile and Asset Management: Efficiency in Decision-Making for Operational Life-Cycle Projects in Transmission System Operators. The paper reconceptualizes a process setup for decision-making related to operational life-cycle project activities within a Transmission System Operator (TSO). While the paper can stand alone, this chapter introduction aims to align its findings with those of previous chapters, establishing a coherent link between agility, digitalization, and asset management.

Building on the prior discussions of agile in Chapter 2 and digitalization in Chapter 3, this chapter extends the conversation by exploring how agile principles can be applied in asset management to enhance decision-making, operational efficiency, and responsiveness to uncertainty. Previous chapters outlined two key dimensions:

- Agile (Chapter 2): Defined as a strategic capability for managing risks and pursuing opportunities in complex industrial environments, agile was framed as a governance, leadership, and operational methodology that balances flexibility with control.
- Digitalization (Chapter 3): Examined as an enabler of asset and maintenance management, digitalization was shown to improve data-driven decision-making, predictive maintenance, and process optimization while revealing gaps in industry-wide digital maturity.

This chapter synthesizes these perspectives by investigating how agile methodologies can enhance asset management through digitalized decision-making. The case study in this publication explores how agile principles - such as iterative workflows, cross-functional collaboration, and real-time adaptability - can be operationalized within OLP, particularly in organizations with complex infrastructure like TSOs.

By integrating agile and digitalization within asset management, this chapter contributes to the dissertation’s overarching argument: that rethinking asset management requires a convergence of flexible methodologies, data-driven insights, and industry-specific operational strategies. The findings in this chapter provide empirical evidence supporting this integration, illustrating how agility can be practically implemented within asset management decision-making to improve responsiveness and efficiency in large-scale operational projects.

Thus, this chapter serves as the final link in the dissertation’s progressive argumentation, demonstrating how agility and digitalization together can redefine asset management for modern industrial contexts.

4.1 Agile and Asset Management: Efficiency in Decision-Making for Operational Life-Cycle Projects in Transmission System Operators

Brasen, L.P.H., Tambo, T. (Resubmitted for review January 2025).

The following journal article answers RQ3.

The paper was submitted to Energy Research & Social Science (Elsevier) and is under review.

The content of this chapter was copied directly from this paper, with minor formatting changes.

Abstract: Integrating Asset Management (AM) and 'Agile' methodologies holds significant potential for enhancing the management and decision-making processes within Transmission System Operators (TSO). TSOs face considerable challenges, including ageing infrastructure, resource constraints, and escalating maintenance and lifecycle enhancement costs. As the transition to renewable energy sources intensifies, the need for transparent and data-driven decision-making becomes increasingly critical. This paper explores implementing a combined AM and Agile process to address these challenges, focusing specifically on operational life-cycle projects (OLP). An applied design science research (DSR) methodology examines the current state of OLP management within a TSO, leading to a new, scalable, agile, and transparent decision-making process. The findings suggest that integrating Agile principles with AM practices can significantly improve flexibility, adaptability, and overall efficiency in project management. Enhanced data utilization and transparency are critical factors in supporting strategic decision-making and aligning with organizational objectives. The study concludes that adopting a combined AM and Agile process can effectively address the operational and sustainability challenges TSOs face, ultimately contributing to transparency, efficiency, and accountability of activities related to power grid management.

Keywords: *Agile, Asset Management, Maintenance, Data-Driven decision-making*

4.1.1 Introduction

The global energy transition necessitates significant changes in energy systems, often focusing on large-scale projects such as wind farms, photovoltaic (PV) farms, transmission lines, and Power-to-X (PtX) plants, as well as the development of integrated distributed solutions like smart grids (Zheng *et al.*, 2022). These projects require substantial investments and are pivotal for achieving decarbonization goals (Klass, 2017; Biancardi, Di Castelnuovo and Staffell, 2021). Transmission System Operators (TSO) are critical in managing national electricity grids and ensuring their reliability during this transition. To address the increasing complexity of grid operations, TSOs have increasingly adopted Asset Management (AM) systems, which offer a structured framework for prioritizing resources and managing asset lifecycles (Schneider *et al.*, 2006; Tjernberg, 2018). Many TSOs have pursued certification under the ISO550xx standards to formalize their AM practices (ISO, 2025).

A significant challenge for TSOs is the ageing grid infrastructure, with approximately 20% of global grids requiring replacement (Hossain, Hossain and Un-Noor, 2018). Additionally, growing electricity consumption, the integration of distributed energy resources (DERs), and the need for grid expansion present operational and strategic challenges (Romero Aguero, Khodaei and Masiello, 2016; Hossain, Hossain and Un-Noor, 2018). Further, most TSOs are quasi-governmental entities operating under close governmental oversight, so funding mechanisms are tight, regulated, and exposed to political considerations. Besides this, many TSOs face more subtle challenges in terms of a shrinking workforce, higher costs associated with maintenance, and complex transitions to sustainable sources of energy where tough decisions must be made (Romero Aguero, Khodaei and Masiello, 2016; Hossain, Hossain and Un-Noor, 2018; Hafner and Tagliapietra, 2020). These factors necessitate effective lifecycle asset management to avoid resource misallocation and to support transparent decision-making, detailing the need for a systemic approach to managing the operational assets of TSOs.

The use of AM to balance the operational and strategic demands of power delivery and sustainable development is driven by various challenges facing the industry (Khuntia *et al.*, 2016). Effective AM practices guide TSOs in managing assets to address these challenges while supporting their strategic objectives (El-Akruti, Dwight and Zhang, 2013). Given the operational and sustainability demands, transparent and data-driven decision-making has become increasingly important. However, while data informs many decisions within a TSO, its application is often inconsistent across different organizational levels. This inconsistency can limit the effectiveness of AM, particularly in areas requiring alignment between operational activities and long-term strategic goals, such as in the Operational Life-cycle Projects (OLP).

OLPs represent a critical aspect of TSOs operational responsibilities. Positioned between routine operational tasks and major infrastructure investments, OLPs are essential for sustaining grid performance and supporting organizational goals. However, their management is often governed by experience rather than robust data-driven processes, posing risks to transparency and efficiency in an increasingly complex operating environment. This paper explores the potential for integrating Agile methodologies and digital tools into Asset Management processes to enhance the management of OLPs. Agile, as a mindset and management framework, promotes adaptability, responsiveness, and iterative decision-making, qualities that complement the structured approach of AM (Crombie, 2016; ISO, 2024). At the same time, digital tools augment the data-driven decision-making capabilities that synergize with the needs of the TSOs and the underlying potential in Asset management systems (Alonso *et al.*, 2023).

The synergy between AM and Agile has gained recognition in recent years, as both methodological approaches emphasize value realization and the alignment of asset investments with organizational goals (Joseph *et al.*, 2018; C Parra *et al.*, 2021). Further, the newest published edition of the ISO 550xx series of standards from 2024 outlines that adaptability is crucial for successful asset management success, thus supporting the synergy between Agile and AM (ISO, 2024). For TSOs, adopting such a combined approach could improve decision-making, optimize lifecycle costs, and enhance the availability and reliability of critical assets (Wan, 2017). Integrating AM and Agile methods aligns with broader digitalization and maintenance management trends. Digital tools and data analytics can enhance transparency and more informed decision-making processes, thus enabling value realization and strategic organizational alignment. Further, Agile's emphasis on flexibility and real-time responsiveness aligns with modern maintenance and asset management practices, such as predictive maintenance and condition-based monitoring, which rely heavily on digital technologies and data analytics. By leveraging these tools within an Agile framework, TSOs can optimize lifecycle costs, improve asset availability, and manage operational risks more effectively (Kabeyi and Olanrewaju, 2022; Kortelainen and Hanski, 2023). This study examines these intersections to propose a more adaptive and data-driven approach to OLP management. Further, the paper presents a case study-driven Design Science Research (DSR) approach to develop a new process for managing OLPs within a TSO. The proposed process leverages internal systems and tools to enhance scalability, transparency, and data-driven decision-making, ensuring alignment with AM and Agile principles.

Main RQ: How can combining Asset Management (AM) and Agile methods improve decision-making and the management of operational life-cycle projects (OLP) in Transmission System Operators (TSOs)?

To answer the main research question, the following sub-questions have been formulated to ensure a systematic approach to addressing the key aspects of the study:

RQ1: What challenges do TSOs face in managing operational life-cycle projects (OLP)?

This sub-question aims to identify the specific hurdles TSOs encounter in managing OLPs. The study lays the groundwork for proposing solutions that align with the main research question by understanding these challenges. Key aspects include the ageing infrastructure, fluctuating energy demands, integration of renewable energy sources, and constraints such as funding and regulatory oversight. These challenges necessitate a clear framework for lifecycle management to ensure that TSOs can maintain grid reliability while adapting to evolving energy demands. Addressing this sub-question provides a critical context for understanding the operational and strategic difficulties that AM and Agile methods seek to resolve.

RQ2: How can Agile methods enhance Asset Management (AM) practices to improve transparency and data-driven decisions in TSOs?

Building on the challenges identified in Sub-question 1, this sub-question explores how Agile methodologies can complement AM practices. Agile emphasizes iterative development, adaptability, and stakeholder collaboration, which can enhance the flexibility and responsiveness of AM frameworks. This section investigates the potential of Agile to improve decision-making processes, foster transparency, and integrate digital tools to support data-driven operations. Addressing this sub-question clarifies how Agile methods can operationalize and strengthen AM practices, providing a more dynamic approach to managing OLPs.

RQ3: What impact will a combined AM and Agile approach, supported by digital tools, have on the scalability, efficiency, and effectiveness of OLP management in TSOs?

The final sub-question evaluates the broader implications of integrating AM and Agile methodologies. By leveraging digital tools and analytics, the study assesses how this combined approach can enhance scalability, streamline operations, and improve overall efficiency in managing OLPs. This section aims to demonstrate the potential benefits of such an integration, providing actionable insights into how TSOs can optimize resource allocation, reduce operational risks, and achieve strategic goals. Addressing this sub-question completes the systematic exploration of how AM and Agile can jointly enhance OLP management, tying back to the main research question.

Thus, this paper aims to provide a comprehensive analysis of how TSOs can address the challenges of managing operational life-cycle projects by integrating AM and Agile methodologies. The study explores how these methods can improve decision-making, enhance scalability, and optimize resource allocation by leveraging digital tools and data-driven approaches. The research questions outlined above will guide the investigation and form the basis of the analysis presented in Section 5 of this paper, where detailed findings and proposed solutions will be discussed.

4.1.2 Theoretical Background

The theoretical background of this study focused on the intersection of Asset Management (AM), Agile methodologies, and the role of the TSO. Asset Management, particularly within TSOs, ensures the efficient operation and lifecycle maintenance of critical infrastructure, adhering to standards such as ISO series 550xx (ISO, 2024). However, as the energy sector shifts towards renewable energy and faces growing complexity, AM practices often need more flexibility for rapid adaptation. Agile methods offer a more dynamic approach to enhance decision-making and responsiveness in managing OLPs. This integration of AM and Agile practices provides TSOs with the potential to improve transparency, efficiency, and data-driven processes in an increasingly complex and evolving energy landscape.

4.1.2.1 Transmission system operator

TSOs are responsible for the operation and maintenance of the national power grid, a critical infrastructure enabling modern societies' dependence on electricity (Pouliot *et al.*, 2020). The power grid has been critical for ensuring that electricity from non-renewable energy sources is transmitted thoroughly and sufficiently. However, with the need for sustainable solutions, the transition to renewable energy sources (RES) has provided many complex challenges among the increasingly ageing assets, technological innovations, regulatory requirements, etc. (Guerrero *et al.*, 2020; Athanasiou, 2023). Furthermore, there is a growing evolution in the demand for power, which is bound to the societal concerns regarding the utilization of RES (Romero Aguero, Khodaei and Masiello, 2016).

Historically, TSOs facilitated the transmission of energy from centralized non-renewable sources to distribution networks. However, the global shift toward RES presents complex challenges, including the integration of distributed energy resources (DERs) like photovoltaics and wind energy (Pollitt, 2012; Ameur *et al.*, 2019; Heern, 2023). This transition demands that TSOs not only upgrade ageing grid infrastructure but also accommodate the variability and decentralization inherent in RES. Additionally, TSOs operate under intense regulatory oversight and must address stakeholder concerns such as grid resilience, cybersecurity, and public acceptance (Romero Aguero, Khodaei and Masiello, 2016; *Integration of Distributed Energy Resources in Power Systems*, 2016; Tuinema *et al.*, 2020).

This transition to DERs is driven by researchers researching the need for scalability of existing RES solutions and their inclusion in countries' power generation mix (Romero Aguero, Khodaei and Masiello, 2016). This is supported by the activities in the TSOs that enable the transmission of power from the suppliers of energy (e.g., power plants, solar, wind, hydroelectric, and nuclear plants) to the distribution service operator (DSO), which is responsible for distributing the electricity to the consumer. However, considering that the traditional power grid is built to accommodate a conventional centralized energy distribution system, retrofitting and developing new grid solutions to accommodate sustainable alternatives have proven difficult (Romero Aguero, Khodaei and Masiello, 2016; Hossain, Hossain and Un-Noor, 2018). These multifaceted challenges require TSOs to rethink traditional operational models and adopt flexible, forward-looking approaches and applied methods. AM provides a structured framework for lifecycle maintenance, while Agile offers adaptive methodologies to address these dynamic demands.

TSOs operate within a complex network of stakeholders, including governmental bodies, non-governmental organizations (NGOs), and commercial entities. Many of these stakeholders prioritize transitioning to RES, placing significant pressure on TSOs to align their operations to address societal and environmental concerns (Romero Aguero, Khodaei and Masiello, 2016). This alignment requires substantial investments in the development, construction and operation of grid infrastructure to support renewable energy initiatives.

However, TSOs face several critical challenges that complicate this transition, including the integration of DERs, the need for grid expansion, and ensuring grid resilience amidst evolving cybersecurity threats (Heern, 2023). Moreover, these challenges are compounded by the ageing infrastructure, public resistance to new grid developments, and the need for international coordination to manage cross-border energy flows. A collection of these challenges is detailed in Table 4-1.

Table 4-1 - Challenges facing TSOs

Integration of RES	One of the primary challenges is integrating renewable energy sources, such as wind and solar, into the existing grid infrastructure. RES tends to be distributed across vast geographical areas and can be intermittent, requiring TSOs to manage variability and ensure grid stability (Romero Aguero, Khodaei and Masiello, 2016).
Grid expansion and upgrades	Accommodating renewable energy often necessitates significant upgrades and expansions to the transmission grid. This includes building new transmission lines, substations, and other infrastructure to connect renewable energy sites to population centers and industrial areas (Wan, 2017). Likewise, the ageing grid is reaching its end of life and needs to be upgraded (Pouliot *et al.*, 2020).
Technological innovation	TSOs must continually invest in and adopt new technologies to enhance grid flexibility, manage power flows efficiently, and incorporate advanced monitoring and control systems, also called smart grids. This often requires substantial financial investment and overcoming regulatory barriers (Radenković *et al.*, 2018; Zheng *et al.*, 2022).
Policy and regulatory frameworks	Regulatory uncertainty and inconsistencies can challenge TSOs in planning and implementing renewable energy projects. Clear and supportive policies are needed to incentivize investments in renewable energy infrastructure and ensure a level playing field for all market participants (Hossain, Hossain and Un-Noor, 2018; Heern, 2023).
Grid resilience and security	As the grid becomes increasingly interconnected and reliant on digital technologies, TSOs face heightened cybersecurity risks. Ensuring the resilience and security of critical infrastructure against cyber threats is essential to maintaining grid reliability and safeguarding energy transition efforts (Hossain, Hossain and Un-Noor, 2018; Wang *et al.*, 2018).
Public acceptance and stakeholder engagement	Local communities often oppose building new transmission infrastructure due to concerns about visual impact, property values, and environmental impacts. Effective stakeholder engagement and transparent communication are essential for gaining public acceptance and navigating regulatory approval processes (Romero Aguero, Khodaei and Masiello, 2016).

International coordination	Many renewable energy resources span multiple countries, such as offshore wind farms and interconnected transmission lines. Coordinating international regulatory frameworks, technical standards, and cross-border grid operations is critical for optimizing the utilization of renewable energy resources and enhancing energy security (Hossain, Hossain and Un-Noor, 2018).
Financing and investment	The transition to renewable energy requires substantial upfront investments in new infrastructure and technologies. To fund these investments while ensuring consumer affordability, TSOs need access to financing mechanisms, such as public-private partnerships and green bonds (Joseph *et al.*, 2018).

Addressing these challenges necessitates a structured and systematic system and process for managing assets throughout their lifecycle. Thus, AMs are used widely across TSOs (ISO, 2025) to facilitate an informed, risk-based decision-making process that ensures consideration of future and current challenges for the TSOs (González-Prida *et al.*, 2022). Risk management is a critical component of AM system setups and is likewise essential for TSOs because it helps mitigate accidents, avoid disruptions, and, consequently, save time and resources (Brasen and Tambo, 2021). By employing these strategies, TSOs can navigate the complex landscape of stakeholder interests while advancing the transition to RES.

Further, the adoption of innovative grid technologies, such as advanced communication systems, automation, and smart grid solutions, has become essential for TSOs to enhance grid flexibility and operational efficiency (Radenković *et al.*, 2018). This is where AM likewise plays a pivotal role. AM provides the tools and frameworks necessary for TSOs to prioritize investments, optimize resource allocation, and maintain critical infrastructure in alignment with strategic objectives (González-Prida *et al.*, 2022). By systematically managing risk, AM helps TSOs mitigate potential disruptions, reduce downtime, and enhance the overall reliability of the grid (Syed and Lawryshyn, 2020; Brasen and Tambo, 2021).

Given the multifaceted challenges TSOs face, AM serves as a foundational framework for navigating these complexities while advancing the transition to RES. The following section explores Asset Management in greater detail, emphasizing its relevance and applicability to addressing the operational and strategic demands of TSOs.

4.1.2.2 Asset Management

The concept of "Asset Management" has evolved over the past four decades, shifting from its original use in financial investment contexts to a broader organizational practice. It now refers to the systematic and coordinated efforts aimed at deriving value from an organization's assets, aligned with its objectives and strategies (Amadi-echendu *et al.*, 2010; ISO 55000 series, 2014; Somia Alfatih, Leong and Hee, 2015). Furthermore, AM employs the use of an interdisciplinary approach to sustaining and managing assets, which has been argued in the literature since the 1990s (Bittner and Rosen, 2004; Wijnia and de Croon, 2015). AM is particularly relevant as it addresses the entire lifecycle of physical assets, a crucial consideration from a sustainability standpoint. AM is founded on the premise that assets are managed to support the organization's strategic goals and objectives. This requires specialized managerial knowledge and expertise spanning multiple organizational disciplines (García-Gómez *et al.*, 2021).

AM is particularly relevant in correlation with TSOs, as many TSOs globally have obtained AM certification (ISO, 2025). Given the significant investments in AM, especially by utility companies and TSOs, it is essential to provide an overview of key aspects related to AM. This includes examining assets, systems, and processes defined by the ISO 550XX series of standards. In the AM context, an asset is defined as any item or entity with potential or actual value to an organization (ISO 55000 series, 2014; Liyanage, 2017a; DS/ISO, 2018). Such assets can influence the organization throughout their lifecycle and encompass tangible, intangible, financial, and non-financial elements (González-Prida *et al.*, 2022). This concept of value serves as the benchmark for organizations engaged in AM, both for certification and theoretical understanding. It also includes engineering assets (Amadi-Echendu *et al.*, 2010), which are physical assets specifically designed to generate business value through strategically acquired capabilities and resources (Khuntia *et al.*, 2016). Examples include powerlines, converters, standby capacities, and control systems. Additionally, the Center for Integrated Engineering Asset Management (CIEAM) categorizes industries where AM is critical, such as state agencies, local governments, transport infrastructure, water facilities, power utilities, manufacturing, mining, defense, educational facilities, and other sectors (García-Gómez *et al.*, 2021).

The ISO 550xx series defines Asset Management as the application of coordinated activities within an organization to generate value from assets (ISO 55000 series, 2014). This concept of value typically involves balancing costs, risks, opportunities, and asset performance (ISO 55000 series, 2014). The term "activities" in this context is broad and encompasses the approaches, planning, and implementation efforts associated with AM (ISO 55000 series, 2014). Building upon this definition, AM can be described as a comprehensive process through which organizations derive value. It is characterized by a managerial framework that integrates strategies, technologies, resources, risk management, and personnel-related change management (García-Gómez *et al.*, 2021).

Understanding the concept of value is fundamental to Asset Management (Amadi-echendu *et al.*, 2010). Since the effectiveness of AM is evaluated based on its ability to create and preserve value from an organization's assets, it is crucial to clarify what value entails (González-Prida *et al.*, 2019). Examples of value may include achieving sustainability goals, fostering a positive working environment for employees, driving innovation, or ensuring profitability. While these examples provide a general sense of what value may represent, the key point is that value within an AM system is directly tied to an organization's objectives and strategies. Consequently, stakeholders play a central role in defining what constitutes value, thereby shaping the criteria against which AM activities are assessed (Brasen and Liyanage, 2022).

AM practices are essential in effectively operating an asset and realizing the asset's value according to the organizational demands. These operational AM practices include performance monitoring, continuous improvement, evaluation of effectiveness, reinvestments, change management, and outsourcing (ISO 55000 series, 2014). Each of these activities is crucial for maximizing the asset's value in alignment with the organization's objectives, ensuring adherence to industrial standards and the academic principles of asset management (DS/ISO, 2018; Ihemegbulem and Baglee, 2020).

An asset's operational phase is typically the longest in its lifecycle, especially in industries such as utilities and infrastructure, where assets are designed to last for several decades and are often stretched way beyond their expected lifetime (Lodgaard, Aschehoug and Powell, 2020). Consequently, robust plans and activities are necessary to support these decade-long lifespans. For instance, performance monitoring ensures that the asset performs as expected and enables certain maintenance activities to be performed on time (Kang *et al.*, 2016). Performance monitoring enables continuous improvements and correlates with an organization's risk management initiatives, which ensure AM compliance and quality. Since the operations of assets aim at creating value, continuous improvement is essential for enhancing the asset's value over time (Van Der Lei, Herder and Wijnia, 2012, p. 158). This is necessary not only due to technological advancements and changes in the operating environment but also because an asset's efficiency and value creation capability tend to degrade over time. Effective continuous improvement initiatives require active participation across all organizational levels, emphasizing collaboration and alignment with strategic objectives (Lodgaard, Aschehoug and Powell, 2020).

However, the complexity and variability of operational environments, particularly in the energy sector, pose significant challenges for AM (Khuntia *et al.*, 2016; Romero Aguero, Khodaei and Masiello, 2016; Hossain, Hossain and Un-Noor, 2018). These challenges demand a level of adaptability that conventional AM approaches may struggle to meet. Agile, as a methodology, offers a potential solution by enabling organizations to respond rapidly to changes while maintaining operational effectiveness (Zielske and Held, 2021).

Agile in the context of AM provides a framework for improving responsiveness, fostering innovation, and enhancing decision-making processes. The combination of AM and Agile methodologies holds promise for TSOs, where the operational landscape is shaped by evolving renewable energy integration, regulatory demands, and ageing infrastructure. It allows TSOs to navigate uncertainties while aligning their practices with long-term strategic goals. Agile, particularly in its intersection with AM, will be explored in the following section to understand its potential to address the unique challenges facing TSOs

4.1.2.3 Agile and AM

As a management paradigm, Agile has existed since the early 1990s but has transformed over the past three decades. Starting as an operational management paradigm for manufacturing processes, the concept of Agile was then adopted into project and IT management and development as a critical feature for flexible and adaptive development projects (Serrador and Pinto, 2015; Gunasekaran *et al.*, 2019). The defining features of an agile system, whether viewed through the lens of manufacturing, IT development, or project management, are that it is created and operated with the intent of adapting to an environment where continuous and unpredictable change can happen, typically with the explicit purpose of creating value, i.e., profitability, etc. (David F, Hasan H and Saya, 2009; Hallgren and Olhager, 2009; Rigby, Sutherland and Takeuchi, 2016). This not only encompasses the requirements of customers but also considerations related to competitive advantages and disadvantages. The dynamic needs of customers in an ever-volatile marketplace are particularly critical, as the ability to handle, produce, and introduce new products that meet these demands is essential for business success (Gunasekaran, 1998).

Agile, as a management paradigm, is significant for companies striving to remain competitive and create value (Routroy, Potdar and Shankar, 2015; Potdar, Routroy and Behera, 2017). Thus, it mirrors the value outlook of asset management. Furthermore, while research regarding the interaction between Agile and asset management is limited, a complementarity exists between the two management paradigms. Considering that asset management professionals are facing increasing challenges due to rising complexity and turbulent operating environments, the proposal of integrating Agile as a means of dealing with uncertainties is relevant (Harris and Carapiet, 2006). The republication of the ISO 550xx series of standards in 2024 introduced adaptability as a critical characteristic of AM (ISO, 2024), detailing the complementarity of the two management paradigms. The principles of flexibility and adaptability are central to the understanding of Agile. As Brasen and Liyanage (2022) articulated: “Industrial agility is the ability to embrace flexibility, adaptability, and readiness for change or to meet stochastic industrial demands. Industrial agile companies embody the mentality that change is an inevitability and, therefore, are always prepared to capitalize on opportunities in the market, to respond to the changing dynamics of an industry proactively, and to gain a unique competitive position in terms of value and risk profile. Business models, processes, strategies, assets, and partnerships are created and maintained to facilitate this mindset, creating a truly agile interface in an ecosystem that is renegotiable and reconfigurable to best fit within the demands of the market, threats, and opportunities in the industry, to better deal with performance uncertainties” (Brasen and Liyanage, 2022).

Different perspectives on Agile exist, encompassing cycle time reduction, responsiveness to change, and configurability or reconfigurability of operations (Gligor, Esmark and Holcomb, 2015). From a foundational perspective, agile management philosophies comprise three distinct processes: control, work, and knowledge (Brasen and Tambo, 2021). Each process correlates to the foundation of agile thinking, a systematic management method built on quality, customer-driven demand, and flexibility. Control processes encompass the array of activities, tools, and techniques designed to regulate the flow of agile management systems. These processes focus on monitoring and guiding the work undertaken, utilizing specific tools in place of extensive documentation (Lill and Wald, 2021). For instance, boards (whether physical or virtual) are employed to track progress, maintain administrative oversight of time and budget, and conduct evaluative meetings at the end of iterations for reflection and review of the project (Brasen and Tambo, 2021).

Work processes focus on the structures and practices that maintain continuity throughout agile projects or applications. This is mainly exemplified through iterative periods that allow for reflection and review, ensuring alignment with customer requirements (Lill and Wald, 2021; Zaina, Sharp and Barroca, 2021). Stand-up meetings are another example of a widely applied work practice, used both by Agile-centric teams and in operational contexts, to evaluate recent work and assign new tasks as necessary (Brasen and Tambo, 2021; Napoleão et al., 2021). The final process, knowledge, pertains to applying and retaining knowledge within an organization or team by utilizing agile methodologies. Certain practices facilitate the appropriate application of knowledge, with iterative work processes being central to this (Napoleão *et al.*, 2021). Iteration enables reflection, review, and adaptation to evolving circumstances, making it applicable to development projects and, also, daily operations (Brasen and Tambo, 2021).

An intriguing aspect of Agile as a management paradigm (with its almost 30-year history) is that the challenges discussed in early literature remain relevant to contemporary organizations. Issues such as heightened consumer expectations, market globalisation, increasing competitiveness, and the constant emergence of new technologies transforming modern production systems and products are still prevalent (Yusuf, Sarhadi and Gunasekaran, 1999).

The challenges TSOs face, including integrating renewable energy sources, grid expansion, and managing ageing assets, demand a multifaceted and adaptive approach. AM provides a foundation for addressing these issues by offering structured, lifecycle-based practices that ensure value creation and risk mitigation. However, as operational environments become increasingly complex and dynamic, TSOs must look beyond traditional AM frameworks to meet evolving demands effectively. Agile methodologies, with their emphasis on flexibility, iterative processes, and responsiveness, present an opportunity to enhance the decision-making and operational practices of TSOs. By integrating Agile principles into AM, TSOs can better navigate uncertainty, improve stakeholder communication, and continuously align operational activities with strategic objectives. This integrated approach can address key operational life-cycle challenges and enable more data-driven and transparent decision-making.

Building on this theoretical foundation, the following section delves into a case study of OLPs within a TSO. It examines how current practices can be improved by integrating Agile and AM principles, culminating in a proposed decision-making framework tailored to the unique challenges of TSO operations

4.1.3 Method and case

4.1.3.1 Methodological considerations

This study adopted Design Science Research (DSR), emphasizing the creation of innovative solutions to improve asset management (AM) and operational life-cycle project (OLP) practices within the Transmission System Operator (TSO). DSR aims to develop and evaluate artefacts (in this case, new processes, frameworks, or systems) through rigorous investigation, ensuring they address complex real-world problems in the TSO asset management landscape. Figure 1 represents the applied approach to the case and the process change.

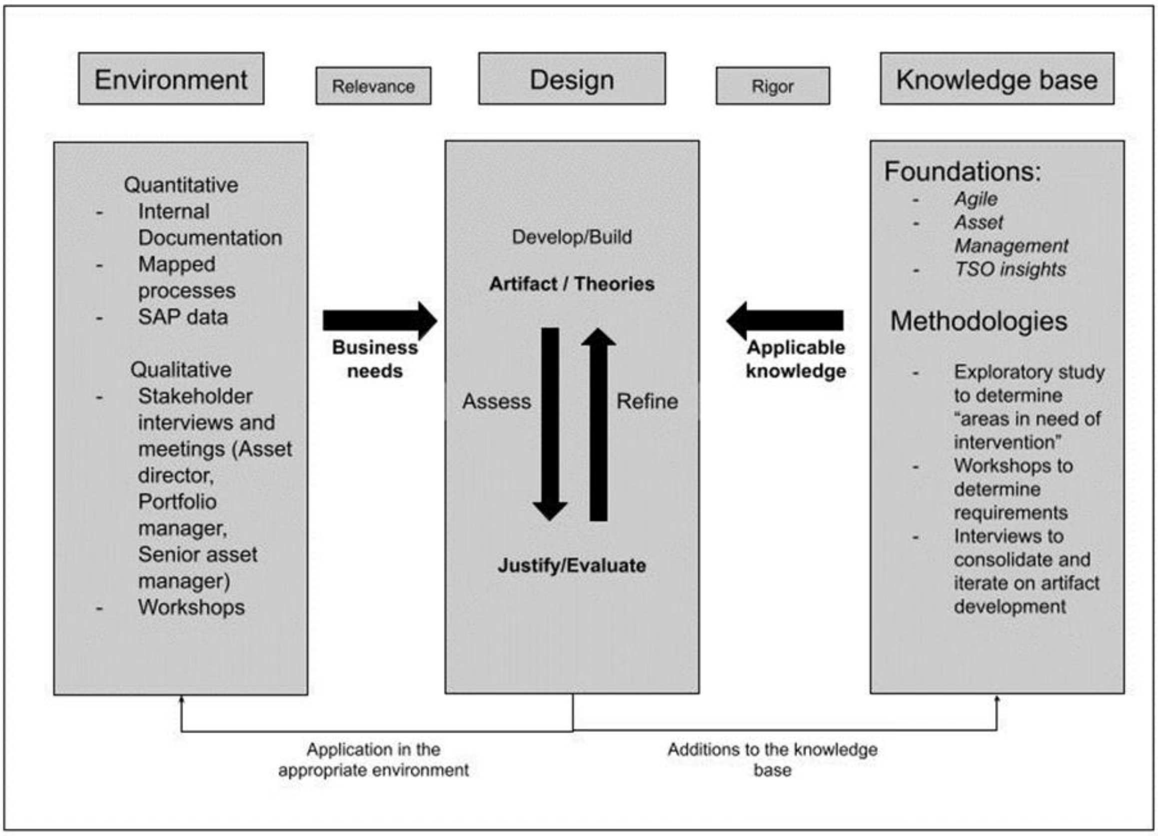

Figure 4-1 - Designed DSR for the case study and artefact development (Inspired by (Hevner et al., 2004; Dresch, Lacerda and Antunes Jr, 2015)

DSR involves an iterative cycle of building and evaluating artefacts in real-world contexts (Hevner *et al.*, 2004; Dresch, Lacerda and Antunes Jr, 2015). The artefact in this study included the new OLP process, which consisted of a framework for decision-making. The iterative process centered on the framework for decision-making allowed for continuous refinement based on feedback from stakeholders and observed outcomes, ensuring that the final solution was aligned with the TSO's needs and strategic objectives.

The study was initiated in collaboration with the TSO to identify inefficiencies in their existing asset management and OLP practices. Table 2 shows the exploratory initial data collection involved an extensive review of internal documentation, systems, and processes.

Table 4-2 - Internal data and documentation from TSO, with description of systems accessed and examples of accessed data

DOCUMENTATION AND SYSTEMS ACCESSED	DESCRIPTIVE OVERVIEW OF CONTENT
INTERNAL ASSET MANAGEMENT SYSTEM	The internal AM system comprised multiple mapped processes and documentation that was related to most activities conducted in the TSO from an Asset perspective. E.g. how the predetermined maintenance process should be performed or specifically related to this case, how OLP activities were prioritized
ERP SYSTEM	Asset registry data and OLP registered activities provided a general and specific overview of the asset and the activities conducted on the assets (Maintenance orders, etc.).

DOCUMENTATION AND CASE-HANDLING SOFTWARE	All documentation produced in the TSO is registered and preserved in this system, and access to all relevant documentation was granted. (E.g. Strategic Asset Management Plan, Project presentations, Organizational overviews)

This was supplemented by interviews and workshops with key personnel, including the Director of Assets and the Portfolio Manager of OLP. An overview of these interviews and workshops is presented in Table 4-3, with a description of the theme/topic covered in the individual sessions. The research identified critical areas requiring improvement, particularly the need for data-driven decision-making in project prioritization, which was found to rely heavily on experiential judgment.

Table 4-3 - Overview of workshops and interviews conducted during the research

SESSION TYPE	PARTICIPANTS	PURPOSE/THEME	DESCRIPTION
DIRECTOR OF ASSET INTERVIEW #1	Director of Assets	Problem exploration and clarification	Initial interview to explore the core challenges in the OLP process, focusing on problem areas and understanding the current limitations and pain points.
WORKSHOP #1	Cross-functional team	Problem clarification and OLP process breakdown	Collaborative session to map out the existing OLP process, identify inefficiencies, and clarify the roles of different departments in project prioritization.
WORKSHOP #2	Cross-functional team	Feature clarification and needs for the New OLP process	Discussion to define the required features and capabilities for an enhanced OLP process, ensuring alignment with the TSO strategic goals and AM principles.
WORKSHOP #3	Stakeholders and process developers	OLP solution development	Brainstorming session focused on co-creating the new OLP process framework, emphasizing transparency, data-driven prioritization, and agile principles.
DIRECTOR OF ASSET INTERVIEW #2	Director of Assets	Feedback session	Follow-up interview to validate the developed OLP process framework and gather feedback for iterative refinement.
WORKSHOP #4	Cross-functional team	Feedback session and future research and development potential	Final workshop to present the refined OLP process, incorporate additional stakeholder input, and identify areas for future development and research.

The primary objective of the research was to design a systematic, transparent, and data-driven process for OLP project prioritization. Based on the insights gathered, the new OLP process was developed to address identified challenges, particularly aligning organizational objectives with agile asset management principles and ISO 55001 standards. The process was designed in collaboration with the stakeholders to ensure that it met the specific needs of the TSO, accommodating OLP projects ranging from €15.000 to €1.5 million.

Workshops and interviews with relevant stakeholders helped define the requirements and challenges, aligning these with features of the new process. The design of the new OLP process was informed by the TSO strategic goals, mainly its focus on maintaining energy availability and supporting the transition to renewable energy. The process integrated more robust data-driven decision-making frameworks to enhance transparency and accountability in project prioritization.

Evaluation of the developed artefacts followed the DSR principle of iterative refinement through real-world applications (Hevner, 2007). The new OLP process was tested with the TSO, incorporating feedback from various departments responsible for asset management, maintenance, and OLP activities. This evaluation phase assessed the process's ability to improve project prioritization, decision-making transparency, and alignment with the TSO's strategic objectives, including compliance with ISO 55001 standards.

4.1.3.2 Case overview

Asset management represents a foundational competence for the TSO and is the only publicly disclosed certified management system. As the operator of critical energy assets on behalf of society, the TSO emphasizes its adherence to and auditing against the ISO 550XX series of standards. Its stated principle reflects this commitment: "We take care of our assets. We do so by following ISO 55001. We do so, as it creates value for society." The TSO structures its organizational activities to align with the overarching strategic objectives outlined by the asset management system (El-Akruti, Dwight and Zhang, 2013). Figure 4-2 presents a structured process that ensures the communication of asset objectives through a clearly defined organizational flow.

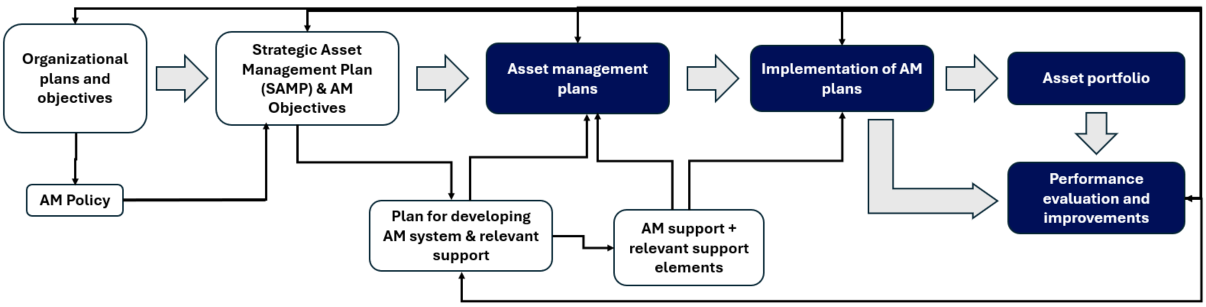

Figure 4-2 - AM process for the TSO

The dark blue boxes within this flow highlight areas where OLP projects are emphasized. While other parts of the process establish the strategic direction, OLP projects are primarily executed within these designated levels of the asset management process.

The organizational plans and objectives of the TSO are shaped by strategies and inputs from its stakeholders and board of directors. TSOs serve as institutional hubs, integrating perspectives from diverse stakeholders across society and international relations. These stakeholders range from governmental entities and consumer interest groups to individual citizens and multinational corporations seeking to withdraw or introduce power into the system. According to the latest strategy, the TSOs priorities include supporting the transition to RES while maintaining high electricity availability within the grid. Unlike earlier strategies, which primarily emphasized availability (energy assurance), the 2023 strategy assigns equal importance to high availability and advancing the green transition. These strategic directives are communicated across the organization through the AM process framework, translating organizational objectives and plans into a

Strategic Asset Management Plan (SAMP). The SAMP then guides the development of specific AM plans that reflect a strategic asset perspective.

As a key player in society's decarbonization efforts, the TSO is tasked with expanding and enhancing the power grid to accommodate anticipated growth in power production, consumption, and transportation. Organizational activities align to support the implementation of AM plans, most notably in the maintenance department, which oversees the electrical grid's operation, maintenance, and life-cycle management. Alongside other departments responsible for asset operations and maintenance, this department manages and develops the TSOs asset portfolio, including OLPs. OLPs are distinct in that they encompass activities that fall outside traditional maintenance frameworks or larger asset revisions.

The OLP portfolio has grown substantially in recent years, driven by several organizational factors. This area of the organization is less constrained by budgetary limitations, accommodates various projects, and demonstrates a high likelihood of project completion within the defined scope. Consequently, maintenance projects that other departments might otherwise manage are often allocated to the OLP portfolio due to its greater capacity to ensure timely completion. Table 4-4 provides an overview of the primary categories of maintenance projects within the OLP portfolio.

Table 4-4 - Overview of maintenance projects in the OLP portfolio

MAINTENANCE PROJECTS	DESCRIPTION
REPLACING PLANT/ASSET COMPONENTS	Components in poor condition are continuously identified as needing replacement. Typically, this is carried out by contractors or internal departments within the TSO, who visit the stations and report observations to the maintenance department. A common feature of all reported replacements is that they are registered with equipment in the ERP system, and their condition is assessed via condition analysis to condition 4 or 5.
IT-REINVESTMENT	IT equipment in the grid has a significantly shorter lifespan than plant/asset components. The systems must support the equipment and ensure that spare parts are available. This activity does not relate to new IT equipment but to reinvestments in IT equipment owned by the asset operator that needs replacing due to end-of-life concerns.
LARGER PERIODIC INSPECTIONS	The larger periodic inspections assess conditions in the existing plants/assets that need to be maintained. The inspection is part of the OLP portfolio of activities, whereas the maintenance activities identified are supplied to the maintenance department.
PURCHASING EQUIPMENT OR LESSER ACQUISITIONS	This OLP activity correlates to purchasing and acquiring tools and equipment with an expected ROI of 3 years or less. These tools can be used to analyze assets, saving money on outsourcing these activities to a contractor.
ELECTRONIC SECURITY AND SURVEILLANCE (ESS)	ESS Components (fences, gates, surveillance, etc.) have a shorter lifespan than plant components (powerlines, power transformers, etc.), which comprise the power grid. Therefore, investments and maintenance activities correlated to ESS are a separate category of OLPs.
COST HEAVY MAINTENANCE TASKS (ABOVE 0.75 MILLION EURO)	The cost-heavy maintenance task is a separate category of OLP, as it is generally beyond the scope of the operating budget of the maintenance department of the TSO. Hence, these expensive maintenance tasks are part of the OLP portfolio as they are part of a separate budget with more flexibility and resources.
REINVESTMENT	This category of OLP assumes that every 3-5 years, a batch of identified components will emerge that, through extended condition analyses, require replacement. The replacements are part of separate business cases and are managed with separate finances. Project managers carry out the activities in the maintenance department.
REINVESTMENT IN THE FLEET OF MACHINERY	The machinery fleet used in daily emergency and maintenance activities and projects is set up as equipment in the ERP system with corresponding lifetimes. Reinvestment in the machinery fleet is carried out according to standard governance for activities between 15.000 euros and under 0.75 million euros; project managers in the department carry out the activity.

While the OLP constitutes a relatively small portion of the TSOs overall budget, it plays a crucial role in supporting the daily maintenance and operation of the power grid. These activities contribute to ongoing value generation and preservation, aligning with agile methodologies and adhering to asset management standards. The value derived from OLP initiatives includes extending asset lifecycles, undertaking minor revisions of asset sites, and facilitating smaller-scale investments and reinvestments.

As TSOs face increasing challenges, including the dual focus on ensuring a successful transition to renewable energy sources and maintaining energy assurance within the grid, there is a growing need to enhance the OLP process. An improved process would allow the TSO to better address these challenges, ensuring alignment with organizational priorities. In particular, the importance of a transparent, valid, and data-driven decision-making framework for managing the OLP project portfolio has become evident.

This understanding was informed by thoroughly examining the TSOs systems and documentation related to OLP portfolio and asset management practices. These efforts were further supplemented by interviews and meetings with the OLP portfolio manager, the director of the Asset Department, and project managers responsible for OLP activities. A key insight from these efforts was identifying challenges in prioritizing maintenance projects within the OLP portfolio. Figure 3 provides an overview of this portfolio's current process for initiating activities.

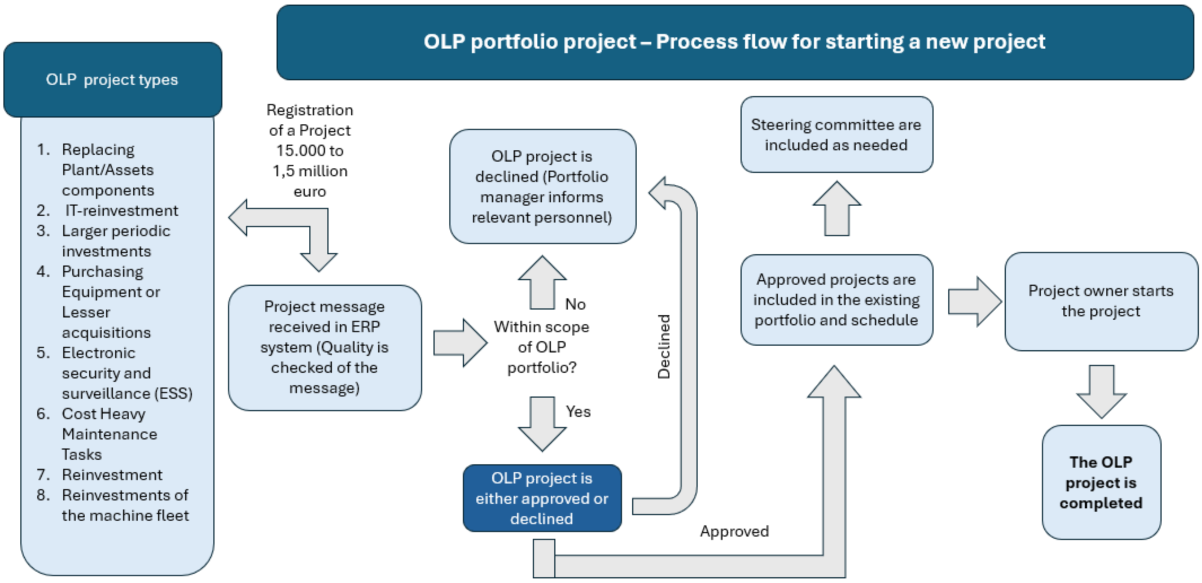

Figure 4-3 - Process flow for starting a new OLP project

Understanding the decision-making process for OLP activities is crucial, as the current process relies heavily on experiential judgment rather than data-driven analysis. This is evident throughout the project registration and initiation phase, as illustrated in Figure 4-3. The critical step in this process is prioritizing which projects will be initiated, specifically deciding the approval or rejection of each OLP project (indicated by the dark blue process). This decision is typically made by the portfolio manager or the steering committee, usually every month. The processes are supported in the ERP system, and all issues are reported digitally as project messages / structured requests, simplified in Table 4-5.

Table 4-5 - ERP message content

ID	Explanation	Example value
NotificationType	Type of the notification	“X1”
NotificationID	Unique identifier for the notification	“2021153”
DesiredStart	The desired start date for the action	"01-09-2025"
Description	A detailed description of the notification	"AA PS - GLN_T41+T42 setup coils"
Responsible	The person or department responsible for the notification	“Jens Jørgen Hansen”
TechnicalLocation	The technical location of the notification	"GLN_400-D01-T41-T41"
TechnicalLocationName	Name of the technical location	"Autotransformer 41"
Equipment	The equipment number associated with the notification	“302807”
EquipmentName	Name of the technical object or equipment	"GLN_400-D01-T41-T41-Autotransformer 41"
ConditionCode	**Describes the condition of the asset numerically**	**1 (asset in good condition) to 5 (asset requiring immediate replacement or life extension)**
ReasonCode	Coding of motivation for the report	
ReasonText	Verbal expression	“Heating anomaly”
SolutionIndication	Verbal expression	“Module replacement needed”
ResponsibleWorkPlace	The workplace responsible for the notification	
Address	The street address associated with the notification	"171 Street, 2345 City"
SystemStatus	The system status of the notification	"MBEH OALL"

The primary quantitative measure utilized in the OLP portfolio is the Condition Code. While this metric is supplemented by experiential judgment, it is limited by the absence of additional data points to support decision-making. Furthermore, the metric’s scope is constrained, as not all activities within the portfolio are directly tied to the asset's condition. For instance, Table 4-4 highlights that some proposed OLPs are unrelated to reinvestments or maintenance, rendering the condition metric either irrelevant or inapplicable. As a result, the prioritization of maintenance projects heavily relies on the experiential knowledge of the registrant and the steering committee.

While experiential judgment remains a valuable resource, sole reliance on it has become increasingly insufficient considering growing political pressures, resource constraints, and the escalating complexity of activities TSOs must undertake. TSOs face the dual challenge of maintaining a robust and reliable power grid while facilitating the transition to renewable energy. Table 4-6 illustrates five examples of OLP projects submitted to the steering committee under the current prioritization framework, which primarily relies on condition-based and experiential evaluations. The information presented for these projects is often limited, with the 'reason for investment' column carrying much of the rationale for the proposed activity.

This underscores the need for a more comprehensive project evaluation and prioritization process. It is important to note that the portfolio manager, the OLP project registrant, and the steering committee deeply understand the organization’s needs and priorities. However, compliance with ISO 550XX certification requires that activities be supported by a data-driven framework that accounts for risk and value creation or preservation. The current reliance on experiential knowledge, coupled with a lack of robust quantitative measures, falls short of meeting this requirement. Therefore, a more transparent, systematic, and data-driven decision-making framework must address these challenges and effectively align with organizational objectives.

Table 4-6 - Current OLP approach - examples

PROJECT	CONDITION	REASON FOR INVESTMENT
EXTENSIONS OF LIFE SPAN	5	The transmission station is approaching end-of-life and is undermaintained. Plans are in the works for a new plant, but that does not happen in the next five years; hence, extending the plant's life span is necessary.
EXCHANGE PLANT ASSETS	NA	Plant assets need to be upgraded to allow new providers to connect and accommodate the transition to renewable energy solutions. Specifically, power transformers and relay protection need to be upgraded.
CABLE SURVEYS	NA	Subsea cables need to be surveyed for potential maintenance. The survey should establish the state of the cables, seabed, and support. Cable surveys need to identify maintenance tasks.
INTERNAL SUPPLY - HVDC	5	Critical components need to be retrofitted and replaced in the internal supply of an HVDC station.
THERMAL CAMERA	NA	Procurement of a high-resolution thermal camera measuring 20-30 meters in height. This will be used to investigate a particular type of composite insulator.

The provided examples, coupled with the significant variability in OLP projects that can be submitted, highlight the diverse and multifaceted nature of the OLP portfolio. Among the examples, only two rely on the condition of the assets as a basis for prioritization within the steering committee. The remaining projects depend heavily on experiential judgment and individual advocacy, creating variability in assessing and prioritizing maintenance projects. Recognizing these limitations, the OLP portfolio manager, the Director of Assets, and senior asset managers have collectively identified the need to develop a more effective, structured solution for planning and prioritizing OLP activities. This acknowledgement emphasizes the growing importance of implementing a systematic, transparent, and data-driven approach to strengthen the decision-making processes governing the OLP portfolio.

Building on this understanding, the subsequent section focuses on developing a new proposed OLP decision-making framework. It explores how current planning and prioritization practices can be refined through a systematic and data-driven approach, integrating Agile methodologies and asset management principles.

4.1.4 Framework development

Several critical considerations must be addressed when analyzing and developing potential solutions for current challenges prioritizing OLP projects within the TSO. First, it is imperative to identify the specific needs involved and examine their correlation with the extensive demands on TSOs and those anticipated in the future. The challenges facing TSOs (see Table 4-1) must be balanced against the OLP process' overarching objectives to facilitate the project portfolio's efficient prioritization. This includes the TSOs overarching strategic objectives, encompassing the assurance of a functioning power grid and the transition to renewable energy. Moreover, the process to align with future objectives should emphasize transparency, data-driven, and risk-based decision-making. This aligns with the strategic vision of the Portfolio Manager and the Steering Committee and ensures a seamless transition towards the sustainable transformation of the power grid (Tjernberg, 2018). Additionally, any new processes developed for OLP portfolio management should comply with Asset Management standards, as detailed in ISO 55000, to ensure audit readiness.

Developing a new process for the OLP portfolio involved the (primarily responsible) portfolio managers and the steering committee, grounding and anchoring the process model in academic principles supported by a theoretical framework. The initial workshop, conducted as a day-long session, identified several valuable features for improving the original process of prioritizing OLP projects. These included integrating the prioritization process into existing systems, visualizing data to facilitate data-driven decision-making, enhancing the OLP portfolio's AM compliance, and improving the overall efficiency of the portfolio management process (see Figure 4-4). Leveraging existing systems and processes minimizes the need to design new systems from the ground up. Furthermore, considering the determined features discussed at the workshop, the possibility of introducing or aligning with an agile approach was considered. This should be done to streamline against the other part of the TSO, specifically the IT department, but also from the consideration that agile process understanding and support, especially from an industrial agile perspective, can improve efficiency and value derived from the activities undertaken. Furthermore, considering that the newest version of the ISO 550XX specifies that adaptability is a necessity for the AM system of the future, embracing adaptability through the lens of Agile is deemed viable. Therefore, it aligns with the determined goal of AM compliance and efficiency improvements.

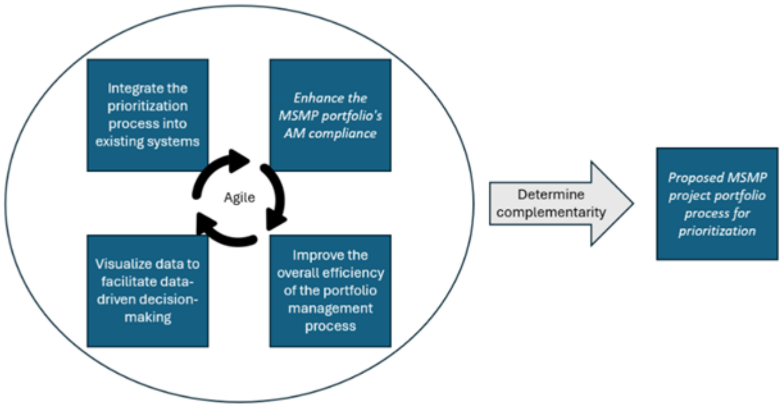

Figure 4-4 - Features of the newly proposed OLP portfolio prioritization process.

The features determined in the initial workshop clarified the direction of the development process and aligned the process towards some of the challenges the TSOs are expected to meet. In the scheme of the TSO, OLP is a small part of accommodating these challenges. However, from the perspective of managing and dealing with the future needs of the TSO, the management system should be able to accommodate even the 'smaller' activities that are corroborated in the organization. The TSO has complete control of the management system when investigating the larger asset operations. However, smaller asset operations, including OLP, lack the strictly precise management requirement. Hence, there is the possibility for improvement. Furthermore, the OLP portfolio is a critical component in piloting an alignment towards the future challenges of the TSO and determining a baseline for a management system that can systematically enable decision-making through a risk-based, transparent, and system-integrated process, which aligns with AM compliance and Agile.

Each of the four features determined in the workshop was designed with complementarity in mind. From the perspective of the TSO, system integration, AM compliance, efficiency improvements, and data visualization are all parts of the greater whole that will make up the new OLP process. Integration in existing systems enables the expansion of the management methodology across the organization if deemed viable and valuable. It also allows for an applied system approach, recognizable by its existing users and personnel and, arguably, limiting resistance to change. AM compliance is a baseline need within the TSOs managerial ecosystem, and certification in the ISO 550XX series is deemed necessary for operating the power grid. Data visualization enables efficiency improvements in the OLP process, considering that data-driven decision-making should support the portfolio manager and the steering committee in prioritizing projects from a transparent and data-driven perspective.

Thus, considering that the four features are complementary, the approach is to determine the point of integration into the TSO. One of the four features' complementarities is agile, a baseline supporting thinking. The agile consideration in the features is especially significant when considering that flexibility, adaptability, and responsiveness to change are essential. It will only succeed if the proposed process can entertain multiple OLP projects. Likewise, if adaptability and responsiveness to change are neglected, the likelihood of implementation failure is significant. Furthermore, since the former systematic process for prioritization was a monthly meeting, where the projects were discussed in plenum, continuing that setup with monthly meetings aligns well with a systematic, iterative setup. This enables continuous improvement and quality control.

AM compliance, value creation/preservation, and risk-based decision-making are essential features of an agile mindset. Integration and alignment with the TSOs risk management efforts are regarded as viable starting points. AM significantly relies on the organization’s risk management efforts to support value creation and risk-based decision-making. The TSOs risk management model categorizes risks and their consequences into six severity levels, rated from 1 to 6. This is compared with the probability of occurrence, also rated from 1 to 6 (see Figure 4-5).

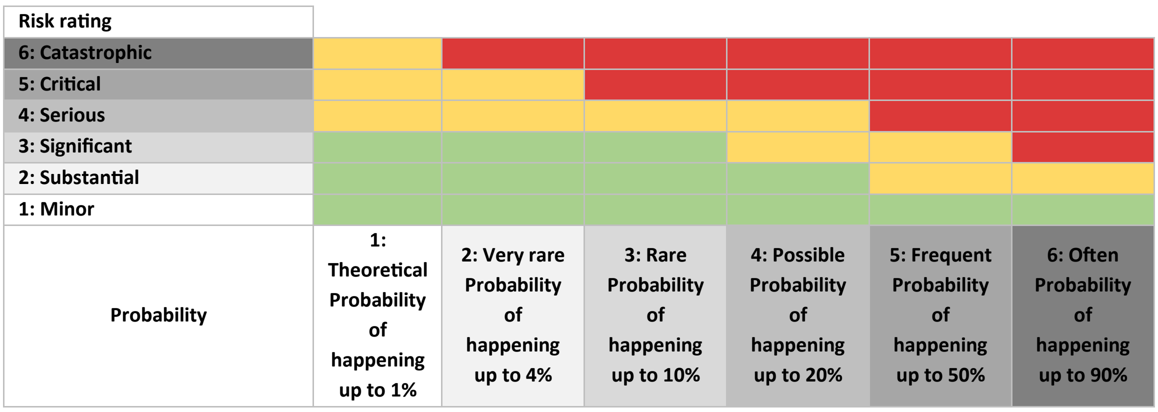

Figure 4-5 - Risk matrix from the TSO

The risk classification matrix, Table 4-7, outlines the TSO’s risk ratings across six categories: Energy Assurance, Economy, Compliance, Environment, Health and Safety, and Trust. These categories encompass most of the organization’s risk profile, including potential equipment downtime or oil leaks from transformers. Table 4-7 details the risk levels from 1 to 6 for each category.

Understanding Table 4-7 and the categorization of risks is crucial for two reasons. First, it aids in prioritizing maintenance projects from an organizational perspective. While Energy Assurance is a primary focus, addressing the other five risk categories is essential due to the TSO’s strategic considerations. For instance, decisions on upgrading power stations to integrate solar and wind energy align with the TSO’s sustainability strategy rather than merely minimizing downtime.

Second, the categorization highlights the significant impact of each risk category on operations. For example, mismanaging trust with suppliers can affect deliverables, and poor economic risk management can lead to higher consumer fees due to increased maintenance costs. Thus, Table 4-7 provides a clear and straightforward method for the TSO to approach risk management comprehensively.

Table 4-7 - Risk classification matrix for prioritization

Risk rating	Energy Assurance	Economy	Compliance	Environment	Health and Safety	Trust
6: Catastrophic	Power out to 60,000+ households for 60+ minutes.	Negative economic effect 5+ MEUR	Missing compliance with internal politics and guidelines is indescribable.	Large-scale pollution that affects the environment for 2+ years	Injury demanding medical attention. 15+ days lost or lasting injury	Significant load on trust. Impact stakeholders with memory of 6-12 months.
5: Critical	Power out to 20,000+ households for 60+ minutes	Negative economic effect 1.5-5.0 MEUR	Missing compliance with internal politics and guidelines happens rarely or never.	Large-scale pollution that affects the environment for up to 2 years	Injury demanding medical attention. 1–14 days lost. No lasting damage	Lesser effect on trust. Impact stakeholder memory 3-6 months
4: Serious	Asset downtime for 24+ hours. No negative end-user effect	The negative economic effect of 0.5-1.5 MEUR		Large-scale pollution that demands substantial cleaning and damage mitigation	Damage that demands medical attention. Work continues with caution. No leave	Limited effect on trust. Up to 3 months of mentions but no external influence on supplier collaboration
3: Significant	Asset downtime for 4-24 hours. No negative end-user effect	The negative economic effect of 0.1-0.5 MEUR		Pollution that demands substantial cleaning and damage mitigation	Damage that demands medical attention. The employee can work the next day	Limited effect on trust. No external influence on collaboration with suppliers
2: Substantial	Asset downtime for 0-4 hours. No negative end-user effect	The negative economic effect of 0.005 -0.100 MEUR		Pollution that needs cleaning and damage mitigation to a smaller degree	An accident that does not need medical attention	Highly limited effect on trust. It may be mentioned in media in 1-4 weeks. No external influence
1: Minor	Error on an asset that demands recalibration	Negative economic effect of <5000 EUR		Pollution can be cleaned up immediately.	Near-miss accidents	Limited or no influence on the trust. Only external mentions

Integrating risk management as the guideline for a prioritization framework aligns with the maintenance projects in the OLP portfolio. Currently, the condition criteria used to determine project initiation primarily focus on the Energy Assurance risk category. However, incorporating the wider risk management framework into the OLP process is beneficial, given its active use within the TSO.

Applying the TSOs risk management setup to the new OLP process introduces a refined consideration to the management system. This process, presented to the portfolio manager, highlights the theoretical advantages of using the risk management framework for the new prioritization model.

Table 4-8 exemplifies this proposed prioritization concept for OLP projects, contrasting with Table 4-6, which represents the current process. The new model integrates risk management criteria, considering the probability and consequence of risks, providing a more comprehensive project assessment. The derived consequence commentary, summarizing the most critical risk, enhances the portfolio manager and steering committee's understanding, thereby improving the decision-making process for approving or declining maintenance projects.

Table 4-8 - Proposed approach for prioritization of OLP projects – selected examples

Project	CONDITION	BUDGET €	PROJECT PERIOD	MOTIVATION FOR INVESTMENT	CONSEQUENCE EVALUATION OF NOT PRIORITISING THE PROJECT							RISK NARRATIVE
					Energy	Economy	Compliance	Environment	Health and	Trust	Probability	
Extensions of the life span of the old power station	5	XX	MM.YY	The transmission station is approaching end-of-life and is under-maintained. Plans are being made for a new plant, but that will not happen in the next five years. Hence, a life-span extension of the plant is necessary.	5	4	NA	6	2	2	5	The possibility of gas leaks is high; hence, the need for lifespan extension is necessary.
Exchange plant assets to enable sustainable transition	NA	XX	MM.YY	To accommodate the transition to renewable energy solutions > plant assets must be upgraded for new providers' connectivity, specifically power transformers and relay protection.	2	4	6	1	1	5	6	The TSO is committed to connecting clients to the grid, reasoning '6' in compliance.
Cable surveys	NA	XX	MM.YY	There is a need to survey subsea cables for potential maintenance. The survey should establish the state of cables, seabed, and support. Maintenance tasks need to be identified through cable surveys.	5	4	NA	5	2	3	4	There is a possibility for significant downtime on the sea cables, affecting the power grid if not maintained properly.
Internal supply - HVDC	5	XX	MM.YY	In the internal supply of an HVDC station, there is a need for retrofitting and replacing critical components	6	5	NA	4	4	2	5	Risk for a lack of supply at the power station affecting energy assurance in the grid.
Thermal camera	NA	XX	MM.YY	Procurement of a high-resolution thermal camera measuring 20-30 m in height. This will be used to investigate a special type of composite insulator.	2	3	NA	2	3	1	3	Risk of large costs associated with unidentified overheating. Affecting energy assurance and the economic situation at the TSO.

Table 4-9 introduces further augmentations to enhance the completeness of the criterion-based prioritization. Each risk category is now associated with distinct data-driven criteria and strategic objectives, detailed beyond the experiences of the relevant personnel. This process ensures that individual experiences do not influence decision-making, promoting a more transparent justification for initiating projects.

While employees' expertise remains invaluable, the goal is to provide a more explicit rationale for project selection. Initially, employee experience is crucial for completing the criteria, but as the proposed process matures and more data becomes available, the process will increasingly rely on empirical data. Nonetheless, the ultimate decision-making authority remains with the steering committee and the portfolio manager, ensuring a balanced integration of experience and data in the prioritization framework.

In summary, the proposed framework is an enhanced decision-making process considering the TSO's existing risk management effort to ensure it aligns with existing internal systems and processes. Furthermore, it complies with AM standards on risk-based decision-making and quantifies the experiences of the technicians and project managers involved in reporting activities for OLP. It embraces Agile by continuing to support the backlog of activities and the prioritization of these in the monthly planning meetings through the quantified data-driven setup, which provides the means of creating a flexible decision-making process that accounts for the needs and wants of the organization, specifically related to the value provided by the specific prioritized activities. It further ensures transparent decision-making that invites accountability for the decisions made.

Table 4-9 - Overview of internal objectives, data, and resources to employ in filing the prioritization criteria.

Overview of internal objectives, data, and resources for assessing prioritization criteria						
Risk category	**Energy Assurance**	**Economy**	**Compliance**	**Environment**	**Health and Safety**	**Trust**
Contact for information	Project owner/registrar of project / System responsible	Operational economists	Compliance officers	Environmental inspectors	Health and safety officers	Purchasing / External communications
Strategic objective	National objectives	Comply with existing economic frameworks	Comply with internal and external laws and regulations	Compliance with laws and regulations on the environment nationally and internationally.	Compliance with worker safety laws, worker satisfaction, and union rights	Trust with legitimacy, credibility, and reputation. Risks affecting the consumer and stakeholders are handled continuously.
Input and data collection	Data logging Operational platforms Staff Observations	Budgets Tariffs Business plans Investments	Law Regulations Standards AM plans	Law Regulations AM plans Incident reports	Law Regulations Incident reports	Supplier communications Public relations Media Observations Public policy

4.1.5 Discussion

This study explored how integrating AM practices with Agile methodologies can improve the management and decision-making processes in OLPs for TSOs. The findings present a promising framework for enhancing risk management, transparency, and accountability within TSOs, responding to the increasing complexity of managing large infrastructural assets, transitioning from centralized to a distributed power generation setup, and transitioning to sustainable energy systems. The main research question and sub-questions are addressed below based on the results obtained.

4.1.5.1 RQ1 - Discussion on challenges for TSOs

The study identified several critical challenges faced by TSOs in managing OLPs, including the reliance on experiential judgments for asset inspections, the complexity of managing a diverse and ageing asset portfolio, and the pressure to maintain high levels of operational availability amidst workforce shortages and the growing demand for renewable energy integration. The findings emphasize that the current system's reliance on qualitative assessments, particularly visual inspections, limits the capacity for transparent and objective decision-making. Additionally, the ongoing transition to renewable energy introduces new layers of complexity. TSOs must balance the operational capabilities of existing assets with the introduction of new, large-scale renewable projects, further straining the already constrained resources.

Moreover, the study highlights the importance of adaptive goal dimensions within asset management. Integrating a transparent, multi-dimensional prioritization tool enables TSOs to align their asset management decisions with evolving organizational goals, whether focused on sustainability, energy assurance, or other strategic objectives. This adaptability ensures that methodological improvements, such as enhanced decision-making frameworks, remain relevant and valuable across different goal settings, regardless of how value is defined within the organization. By embedding flexibility into the decision-making process, TSOs can more effectively adjust to shifting priorities, integrating sustainability targets or other emerging goals without compromising operational efficiency or asset reliability.

4.1.5.2 RQ2 - Agility in AM and data-driven decision-making for TSOs

Agile methodologies complement AM by offering a dynamic, iterative approach to managing the operational life cycle of assets, which allows for continuous feedback and re-prioritization of projects based on real-time data and evolving operational conditions. The study demonstrates that incorporating Agile principles into the AM framework introduces a flexible decision-making model that facilitates fast-paced adjustments and enhances transparency by linking project prioritization to quantifiable risks and asset conditions. This is a significant improvement over the traditional approach, which often depends on static, periodic reviews. Agile's emphasis on collaboration and rapid iteration ensures that decision-makers can access updated and relevant data, fostering more informed and transparent governance. This is particularly crucial for TSOs facing the dual challenge of maintaining existing assets and integrating renewable energy systems.

4.1.5.3 RQ3 - Rethinking OLP in TSOs

The study projects several positive outcomes from implementing a combined AM and Agile approach. First, the scalability of OLP management is enhanced by a framework that can adapt to the growing complexity of TSO operations, especially as digital tools and renewable energy sources become integral to grid management. Including Agile methodologies ensures that the system remains responsive to emerging challenges, enabling TSOs to manage small-scale routine tasks and large, complex projects, like grid expansions or renewable energy integration, with greater Agile.

Second, the efficiency of OLP management is improved by streamlining the decision-making process using data-driven prioritization mechanisms. This eliminates delays caused by subjective decision-making and ensures that resources are allocated more effectively, particularly in asset maintenance and upgrades. The iterative process of Agile helps to quickly identify and address inefficiencies, while AM provides the necessary structure to ensure long-term operational success.

Finally, a more transparent, accountable, and adaptable system bolsters the effectiveness of OLP management. This integrated approach enhances the clarity of decision-making processes and strengthens the alignment of operational activities with the TSOs goals. By improving risk management, asset performance, and governance, TSOs are better equipped to maintain their services' reliability and support the transition to renewable energy while ensuring operational resilience.

4.1.5.4 Integration of AM and Agile

The results indicate that integrating AM and Agile methodologies can enhance decision-making by introducing a structured yet flexible framework that addresses both qualitative and quantitative aspects of project portfolio management. The new framework allows for better prioritization of OLP activities by quantifying experiential insights from project managers and technicians, which were previously based predominantly on visual inspections. This combination leads to more data-driven decision-making, ensuring transparency and accountability while allowing for rapid adjustments in response to changing operational demands, a hallmark of Agile methodologies. Overall, this integration addresses key challenges in OLP management by enhancing the clarity and justifiability of project prioritization decisions, ultimately contributing to more effective asset management.

4.1.5.5 Methodological considerations

This research contributes to both the theory of asset management and the practice of managing operational life-cycle projects in a complex, multi-stakeholder environment. The developed OLP process aligns with DSR's goal of creating innovative, practical solutions while advancing theoretical understanding in asset management. The artefact developed in this study, such as the data-driven decision-making framework, can be applied to other TSOs or organizations facing similar challenges in project prioritization and asset lifecycle management.

By adopting DSR, this study not only developed a more effective and data-driven process for OLP project prioritization but also contributed valuable insights into the application of DSR in asset management. The iterative design and evaluation phases ensured the solution was practical and aligned with the TSO's strategic objectives, offering a model for future research and implementation in similar contexts.

This study has taken a predominantly qualitative approach. The multi-dimensional risk management system, the fast-paced (agile) re-prioritization of the portfolio, the alignment with the asset management system, and the delicate balance between energy assurance and sustainable transition can be represented quantitatively. However, a qualitative analysis presents a string of advantages. The balance between energy assurance and green transition is both a technical and a social process. The technical process is related to the availability of the right technical resources, e.g., a thermal camera. Social processes can deal with the lack of popular support for renewable energy if an extended outage exists. Thus, qualitative research has positively assured the outcome at this stage and in the DSR approach with the TSO. Furthermore, considering that the proposed framework builds upon the quantification of qualitative observations and inherent experience in the technicians, a qualitative methodological approach was deemed viable.

4.1.5.6 Implications

Integrating Agile into AM practices has profound implications for the sustainable transition of energy systems. These energy systems depend entirely on a well-functioning grid with all transmission and distribution system elements in place. Here, the existing portfolio of TSO assets is fundamental but, as illustrated, only with proper life-cycle management as represented by the Asset Management certification philosophy. The stipulated approach suggests that a particular portion of the underlying operational activities determines the overall transition by aiming to continuously improve the grid assets and carefully plan operational life-cycle projects. Improvements and maintenance should ensure that assets are fully operational until their end-of-life. Assets must be maintained at 100% performance capability throughout their lifetime, with their remaining lifespan closely aligned with their planned replacement. Additionally, the energy system transition must balance the operational capability of existing assets, OLP funding for these assets, the introduction of mega-projects, and the necessary OLP funding for new assets. Research supporting the transition must consider the operational capability of the TSO and the governance of OLP to ensure a successful transition. By improving the efficiency and transparency of OLP management, TSOs can maintain their existing infrastructure at optimal performance levels while adopting renewable energy technologies. Focusing on maintaining current assets and supporting new energy projects is crucial for achieving energy assurance and sustainability goals.

Additionally, the proposed framework aligns with global efforts to promote transparent governance, risk-based decision-making, and accountability, which are critical to supporting the sustainable development of energy infrastructure. The process underscores the importance of integrating data-driven practices with flexible, iterative project management techniques to navigate energy transmission systems' complex and evolving landscape.

4.1.6 Conclusion

Given the TSO's uniquely critical role in society, its capabilities must reflect this significance. The organization should exemplify top-tier management practices, ensuring reliable consumer power supply and effectively addressing highly diverse stakeholder demands. Although the OLP process constitutes a small part of the framework, implementing a management model compliant with asset management standards and employing quantitative and qualitative approaches focused on risk management within the OLP portfolio is essential to support this objective.

For the TSO to sustain the transition to renewable energy and ensure energy assurance with 99.9% availability, a new process for managing the activities surrounding the TSO's assets is necessary. Experience-based management must switch to formalized processes with the increasing mean average age of the total pool of assets, an ailing and increasingly scarce workforce, and drivers of professionalism and transparency. The proposed framework for prioritizing OLP encompasses these considerations. Specifically, it is essential to understand that a tool can be used to consciously determine a prioritized view of which activity to activate compared to another.

AM, as described in the ISO 550XX series of standards, is, in essence, a management system providing processes for prioritization, transparency, documentation, and lines of responsibility. This article's proposed set of prioritization mechanisms ensures a smoother alignment between necessary operationally driven activities and the overall objectives of critical infrastructural elements. Thus, the 'mega-project' thinking of green energy assets is insufficient to provide the highest possible level of energy assurance; the set of activities keeping the total pool of assets running must be well understood, well managed, and well prioritized, as outlined in this article.

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

Statement: During the preparation of this work, the author(s) used ChatGPT-4o to strengthen readability. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the publication's content.

Declaration of Competing Interest

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

Data availability

The authors do not have permission to share data.

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5 Chapter 5. – Findings, discussions, implications and conclusion

The concluding chapter sets out to provide a comprehensive reflection on the findings and methodologies articulated within this dissertation, enriched by personal introspection. Subsequently, it will present the scientific and practical implications, offering recommendations for future research directions.

5.1 Findings and Discussions on results

The dissertation has explored the evolution of Engineering Asset Management concerning the interaction with Agility and Digitalization. To achieve this, the research was structured around a main research question and three distinct sub question. Each research question will be discussed in the following, and significant research findings will be highlighted and contextualized. To contextualize the findings from the three sub questions and the main research question, figure 5-1 have been developed. It shows an overview of the extensive complexity that organizations in the industrial eco-system face. From internal complexity related to the aging mass of skilled workers (Peruzzini and Pellicciari, 2017), to external complexity driven by risks and opportunities affecting the global supply chain and economic sphere within which these organizations operate (Amadi-Echendu Joeand Ramlal, 2021). Further, while figure 5-1 details some examples of complexity drivers, it only scratches the surface of the issues organizations are facing today. While in no way extensive, the figure was developed to briefly illuminate the argument that is present in most publications on agile, asset management and digitalization, that companies exist and operate in complex environments with uncertainties abound (Kettunen, 2009; Parlikad and Jafari, 2016; Alsyouf *et al.*, 2018). Thus, arguing for solutions to eliminate or alleviate some of this turbulence, is coincidentally what the discussion on the findings will present.

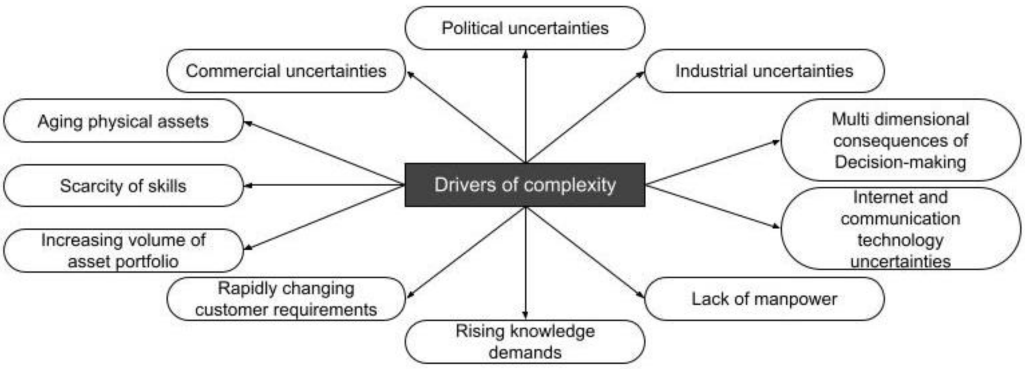

Figure 5-1 - Potential drivers of complexity in a modern organization

5.1.1 RQ1 - What does a conceptual and practical framework for agile in the context of EAM/AM look like?

A central finding of RQ1 is the clarification of agile as a foundational concept, thoroughly explored in two distinct publications. The first publication (see 2.1.) delves into the context and key processes that underpin agile methodologies, while the second publication argues for a refined definition of agile that addresses the specific demands of the industrial sector - demands that existing agile frameworks in manufacturing or software development often fail to fully encompass. Additionally, while previous publications (Baskarada, Gao and Koronios, 2006; Harris and Carapiet, 2006a; Crombie, 2016) have investigated the overlap between asset management and agile, the work done in this dissertation directly links the two in an artifact developed to illustrate the intricate relationship between industrial agility and engineering assets within the broader industrial ecosystem.

Since their inception in the 1990s, agile principles have become increasingly relevant for managing operations, product development, and software development. Agile methodologies have evolved to become integral components of organizational planning, project development, and management theory. This evolution is driven by the escalating demands on industrial organizations, which are facing heightened volatility and uncertainty. The complexity and competitiveness of modern industries have necessitated the development of numerous agile frameworks.

Agile methodologies, with their emphasis on iterative processes and flexibility, offer substantial benefits by enhancing operational efficiency and adaptability. The three proposed processes - control, work, and knowledge management - highlighted in the first publication, are critical for effective agile leadership and governance. These processes are summarized in Table 5-1 and underscore the transformative potential of agile methodologies. By enabling organizations to tailor agile practices to their specific needs and contexts, the proposed processes highlight the promise of agility in transforming traditional project, asset and operation management approaches.

Key processes of agile	
Control	Controlling the flow of agile, tracking the work conducted, with specific tools rather than extensive documentation.
Work	Focuses on the structure and practices applied throughout agile projects or applications.
Knowledge	The application and retention of knowledge within the organization or teams using agile

Table 5-1 - Key processes of agile

Building upon the findings of the first publication, the second publication investigated and defined the notion of industrial agility as a core strategic capability for continuous competitive performance.

Industrial agility encompasses the ability to embrace flexibility, adaptability, and readiness for change to meet stochastic industrial demands. Agile industrial companies embody the mentality that change is inevitable and therefore remain prepared to capitalize on market opportunities, respond proactively to industry dynamics, and secure a unique competitive position in terms of value and risk profile. Business models, processes, strategies, assets, and partnerships are designed and maintained to facilitate this mindset, creating a truly agile interface within an ecosystem that is renegotiable and reconfigurable to best meet market demands, threats, and opportunities, thereby better managing performance uncertainties (Brasen and Liyanage, 2022).

Furthermore, the creation and articulation of an artifact contextualizing the engineering asset from an ecosystem perspective was undertaken. This visual artifact allowed for deliberation on the interface levels of this system, emphasizing the contextualization of the engineering asset within a framework that embraces industrial agility. By vertically and horizontally integrating the concept of agility, the artifact highlights potential interactions that could benefit from "agile intervention."

The essence of agility lies in its adaptability, enabling organizations to selectively implement iterative methods and specific practices that align with their operational objectives. Despite the challenges and diverse opinions surrounding its application, the tangible benefits of agility in terms of efficiency and flexibility make it a valuable consideration for organizations seeking to enhance their operational performance. However, it is crucial to acknowledge that agility is not a one-size-fits-all solution. Different companies have varying needs, and the selective application of agile principles can provide substantial benefits. By focusing on flexibility and adaptability, organizations can better navigate the complexities of modern markets, which are influenced by diverse commercial, political, socio-economic, and information and communication (ICT)-related uncertainties.

In summary, the findings of RQ1 underscore the importance of agility in contemporary industrial practices. The detailed exploration and redefinition of agile principles offer valuable insights for organizations seeking to navigate the complexities of modern industrial ecosystems through flexible and iterative methodologies.

Refined Concept of Industrial Agility	The research redefines agility as a strategic capability tailored to the specific demands of the industrial sector, highlighting its crucial role in enabling organizations to remain flexible, adaptable, and responsive to market dynamics, which are essential for maintaining competitive performance in volatile environments.
Integration of Agility with Asset Management	The research directly links agile methodologies with engineering asset management by developing an artifact that contextualizes engineering assets within an agile industrial ecosystem. This connection emphasizes how agility can transform traditional approaches to project, asset, and operation management.
Tailored Agile Processes for Industrial Application	The proposed agile processes, control, work, and knowledge management are identified as critical for effective leadership and governance in industrial contexts. These processes offer organizations the ability to customize agile practices to their unique operational needs, thus enhancing both operational efficiency and strategic alignment.

Table 5-2 - Valuable insights obtained on agile principles and asset management

The findings from the first chapter and RQ1 define a significant part of the foundation for the work conducted in Chapter 4's paper. For instance, while not explicitly stated in the article in Chapter 4, this artifact was used extensively to map out the intricacies of the TSO's activities related to their engineering assets and the surrounding ecosystem. While it did not fit within the content scope of the paper in Chapter 4, it played a crucial role in the initial stages of the study by helping visualize and demonstrate connections between the assets, their respective support systems, performance objectives, and potential risks. Furthermore, part of the theoretical backbone of Paper 4 is based on the previous work done in Papers 1 and 2. Building on this foundation, the case study findings underscore how integrating AM and Agile methodologies enhances decision-making in project portfolio management. The structured yet flexible framework developed in the study facilitates better prioritization of OLP activities by quantifying experiential insights from project managers and technicians, insights that were previously based predominantly on visual inspections. This integration enables more data-driven decision-making, ensuring transparency and accountability while allowing for rapid adjustments in response to changing operational demands, a hallmark of Agile methodologies.

By aligning with the broader discussion on agility in industrial ecosystems, these findings further emphasize the strategic role of agility in engineering asset management. The study illustrates how agility not only improves operational efficiency but also strengthens governance structures, enabling organizations to remain adaptable and responsive in dynamic environments. This connection reinforces the redefined perspective of agility as a critical capability that supports structured yet flexible decision-making, enhancing the clarity, justifiability, and effectiveness of asset management processes.

5.1.2 RQ2 - What does a conceptual and practical foundation for Digitalization in the context of EAM/AM look like?

The central findings related to RQ2 are derived from two distinct publications. The first publication investigates the relationship between data maturity and maintenance strategy. Data maturity refers to an organization's capability to plan, collect, process, enrich, decide, and operate based on IoT-inspired sensor networks. Assessing both current and desired data maturity levels is crucial for informing maintenance strategies. For instance, predictive maintenance, driven by high data maturity, cannot replace scheduled maintenance if regulatory compliance remains a primary concern. Digitalizing data and processes facilitate the seamless integration of systems, thereby enhancing overall efficiency and providing a competitive advantage.

There is a persistent misunderstanding within practitioner communities that asset management and maintenance are synonymous. The literature clearly differentiates between the two: asset management involves performing integrated activities to realize value from a system's assets, whereas traditional maintenance engineering, despite a similar focus on system reliability, does not extend to the broader objectives of AM, such as performance enhancement and stakeholder value delivery (Petchrompo and Parlikad, 2019a). However, the importance of maintenance and the role of digitalization within maintenance and AM should not be underestimated. Maintenance activities are critical for maximizing the profitability of the asset, with the preservation and restoration, signifying the specific functions of maintenance activities (C Parra et al., 2021a). Thus, with maintenance activities being critical for profitability maximization, which directly influences value creation, a key component of AM activities, considering investments in data maturity can enhance these activities. It is essential that such investments align with the organization’s AM objectives and strategies.

Despite the recognized benefits (saving cost, transparency, improved turnaround times, sustainability benefits, automatic data collection, etc. (Parviainen *et al.*, 2017)), the second publication reveals a lag in digitalization efforts among many organizations, highlighting the need for a stronger focus on the fundamental aspects of digitalization and its integration with asset management. Denmark, a leader in the digital economy (InvestinDK, 2024), shows lower levels of digital maturity among industry professionals according to their own scoring. This discrepancy suggests potential skepticism or other barriers to digital adoption within the industry. The analysis of data presents a mixed picture of digital maturity across organizations: some companies exhibit advanced digital capabilities, while others lag significantly. This spectrum of digital maturity levels indicates the necessity for greater focus on digitalization, particularly in aligning digital capabilities with operational and strategic goals.

Furthermore, there is potential for improvement in both explicit and implicit applications of digitalization. Explicit applications, being something like mobile solution for on-site reporting, whereas implicit, could be whether job descriptions exist for preventive tasks. This observation extends to foundational activities, which currently lack a clear correlation with digitalization. Prioritizing improvements in foundational activities is essential, as these constitute the basic operational requirements or the 'license to operate'. I.e. basic maintenance processes and activities could be one such fundamental activity. Introducing complexity through new technologies and processes should follow these fundamental improvements. Moreover, it is crucial to identify the inhibitors and drivers of digitalization, such as cost, complexity, value creation, and skill levels within the organization. Understanding the current state, needs, and influences within the organization can help assess the impact of digitalization on these factors. Analyzing how digitalization affects these drivers and inhibitors will provide a clearer pathway for implementing effective digital strategies.

Overall, the approach should ensure that foundational activities are optimized first, thereby laying a robust groundwork for subsequent digitalization efforts. This strategy ensures that digital transformation efforts are both meaningful and sustainable, ultimately leading to enhanced operational efficiency and value creation.

In summary, the findings related to RQ2 emphasize the crucial role of data maturity in informing maintenance strategies and the broader objectives of Asset Management. The distinction between asset management and maintenance is essential, as is the alignment of digitalization efforts with organizational objectives. Despite the potential benefits, many organizations exhibit varying levels of digital maturity, indicating a need for a stronger focus on fundamental digitalization aspects. Prioritizing foundational activities is vital to establishing a robust basis for subsequent digital transformation. Identifying and addressing the inhibitors and drivers of digitalization, such as cost, complexity, value creation, and skill levels, will facilitate more effective implementation of digital strategies. Ultimately, optimizing foundational activities before advancing digitalization ensures that transformation efforts are sustainable, enhancing overall operational efficiency and value creation.

In contrast to the findings on agile, the findings from the second chapter and publication 3 and 4 on digitalization are discussed to a lesser extent in chapter 4's publication. Unlike Agile, which is relatively new in asset management, digitalization, data-driven decision-making, and system integration are well-established. For the examined TSO, nearly all maintenance and asset management activities are managed within an ERP system or other essential digital platforms. The question was never whether the proposed decision-making process should integrate into this digital infrastructure, it was a given. However, this reinforces the necessity of a well-integrated asset management system that supports visualization, classification, and strategic prioritization of assets at all levels, from entire infrastructures down to individual components and spare parts.

5.1.3 RQ3 - How can an applied EAM intervention that builds on agility and digitalization, enable AM compliance and the advancement of operational goals and objectives?

Research Question 3 (RQ3) investigates how an applied Engineering Asset Management intervention, leveraging agile methodologies and digitalization, can enable EAM compliance and advance operational goals and objectives. This inquiry builds on previous findings and underscores the importance of developing an artifact that integrates these principles within asset management.

Data collected from the case company guided the creation of an artifact that embodies agile and digitalization principles. This research revealed a significant gap: while large projects adhered to certification requirements, smaller activities often did not. The proposed artifact addresses this gap by ensuring comprehensive compliance and optimizing asset performance. This dynamic AM framework provides substantial benefits, creating a responsive system aligned with contemporary market complexities and maintaining a competitive edge.

The findings contribute significantly to the field of asset management, particularly within the context of the case company. The proposed framework integrates agility and digitalization, enhancing operational goals and compliance. Through detailed exploration of the case company's operations, it was discovered that the company faces critical challenges such as the integration of digital tools, the transition to sustainable practices, manpower shortages, and skill gaps. The framework emphasizes the need for transparent internal processes extending beyond informal practices, which is vital for addressing these future challenges. Figure 5-2 builds on the findings from the publication and contextualizes some of the potential drivers for complexity presented in figure 5-1, as the initiating factor for the creation of the proposed artifact. Further, it concisely presents the derived benefits and learnings, that are applicable beyond the initial proposed artifact.

Figure 5-2 - Drivers of complexity and derived benefits of the proposed artifact

The case company's critical role in its industry necessitates top-tier management practices to ensure reliable operations and meet diverse stakeholder demands. Implementing a management model compliant with AM/EAM standards, incorporating both quantitative and qualitative risk management approaches, is essential for supporting the sustainable transition and maintaining high operational availability. The proposed framework enhances decision-making processes, ensuring a balanced and strategic approach to managing the company's assets amidst increasing challenges.
The evolution of engineering asset management in the context of industrial agility and digitalization reflects a dynamic interaction between traditional practices and modern technological advancements. Agility offers a framework for flexibility and efficiency, while digitalization enhances data integration and operational capabilities. Together, they form a robust foundation for organizations navigating contemporary market complexities and maintaining a competitive edge.

As industries evolve, the principles of agility and digitalization will remain critical drivers of success, requiring ongoing adaptation and strategic implementation. The integration of these principles into EAM provides a comprehensive approach to addressing an organization’s strategic, operational, and technological demands. The theoretical baselines for agile and digitalization practices form the foundation for developing effective asset management strategies. Applied interventions based on these principles can enhance compliance, efficiency, and strategic alignment, ultimately supporting the organization’s overall goals and objectives. Thus, the proposed framework is a forward-thinking model poised to drive significant improvements in asset management, compliance, and operational efficiency. By integrating agility and digitalization, the case company can meet future challenges and maintain a competitive edge, ensuring reliable operations and addressing the complexities of contemporary markets.

5.1.4 Main RQ - How can Engineering Asset Management through integration with agility and digitalization, enable better navigation of an organizations strategic, operational and technological demands?

The overarching RQ provided a fundamental framework for this dissertation and established the context for the work undertaken. It served as a guiding principle rather than a query with a definitive answer, leading the research efforts throughout the study. This approach aligns with the pragmatic research design adopted for the dissertation, aiming to approximate an answer through empirical investigation and theoretical exploration.

Asset management has become a significant and viable management methodology, particularly in sectors like utilities and public transport, where it heavily influences and guides efforts toward better management of owned and operated assets. As described in the ISO 5500x series of standards, AM is essentially a management system that provides processes for prioritization, transparency, documentation, and line of responsibility, ensuring value is created or maintained in relation to the asset. With the detail that value reflects the goals, objectives and strategies that are established by the stakeholders of the company.

The evolution of engineering asset management in the context of industrial agility and digitalization reflects a dynamic interaction between traditional practices and modern technological advancements. Agility offers a framework for flexibility and efficiency, allowing organizations to quickly adapt to changes and optimize their processes. Digitalization enhances data integration and operational capabilities, providing real-time insights and streamlined operations. Together, these elements form a robust foundation for organizations aiming to navigate contemporary market complexities and maintain a competitive edge.

Benefits of Integration

- Flexibility and Efficiency - Agility provides a framework that helps organizations remain flexible and efficient, enabling rapid adaptation to changing market conditions and operational demands.
- Enhanced Data Integration - Digitalization facilitates the seamless integration of data across various systems, improving decision-making and operational transparency.
- Improved Asset Performance - The combination of agile methodologies and digital tools helps optimize asset performance by ensuring comprehensive compliance and efficient management of both large projects and smaller activities.
- Strategic Decision-Making - The integration of agility and digitalization supports strategic decision-making by providing accurate, real-time data and a clear understanding of asset priorities.

The interaction and integration of agility and digitalization with EAM provide a comprehensive approach to addressing an organization's strategic, operational, and technological demands. This comprehensive approach is crucial for industries facing rapid changes and increasing complexity. The theoretical foundations for agile and digitalization practices form the basis for developing effective asset management strategies, enabling organizations to align their operational activities with broader strategic goals.

Applied interventions based on the principles of agility and digitalization can enhance compliance, efficiency, and strategic alignment. These interventions support the organization's overall goals and objectives by providing a framework for better managing resources, optimizing processes, and ensuring that all activities contribute to the organization's success.

The dissertation has developed theoretical abstractions from industrial case company, reflecting the effort involved in the research process. This includes identifying and recruiting the company, scoping individual case studies and relevant problems, and understanding the business operations. These practical steps were essential for grounding the research in real-world contexts and ensuring that the findings and proposed frameworks are applicable and beneficial to actual business practices.

In conclusion, integrating agility and digitalization with Engineering Asset Management provides a robust and comprehensive approach to navigating an organization's strategic, operational, and technological demands. This integration enables organizations to be more responsive, adaptive, and efficient, aligning asset management with broader organizational goals and market dynamics. As industries continue to evolve, the principles of agility and digitalization will remain critical drivers of success, requiring ongoing adaptation and strategic implementation to fully realize their potential. The research conducted in this dissertation underscores the importance of these principles and offers a forward-thinking model poised to drive significant improvements in asset management, compliance, and overall operational efficiency.

5.2 Reflections on methodology

This research has embraced a pragmatic approach to participatory research to understand the application and evolution of Asset Management. This methodological approach while necessary to gaining deep insights, have presented some inherent challenges, which have significantly shaped the research findings.

The principal advantage of the research methodology lies in its capacity for close engagement with the subject matter. By integrating deeply into communities of practice and relevant organizations compliant with Asset Management standards, the study has garnered a comprehensive understanding of the realities and challenges faced by Asset Management practitioners. This proximity to practical communities and organizational issues has enabled an in-depth exploration of deeply rooted problems, allowing for their thorough examination and resolution. Consequently, the research has yielded unique insights into Asset Management compliance and adherence. This approach has imparted a sense of authenticity and comprehensiveness to the project, ensuring that the research remains pertinent to the industry and that the proposed solutions are feasible for organizations interested in Asset Management.

However, this approach also presented challenges, particularly in data collection, which must be acknowledged. The absence of a pre-defined focus during interactions with the communities of practice and organizations compliant with Asset Management standards led to a more opportunistic and context-driven process. Although this method facilitated the acquisition of data relevant to the immediate context, it impeded the ability to achieve a comprehensive understanding of the collected data. To address this, ongoing contextualization, towards the solution space and the available literature became essential. Further, to ensure a degree of robustness to the findings, ongoing interactions with the communities of practice and companies executing asset management, was performed to obtain feedback and relevant empirical insights.

For future research endeavors, it is essential to improve and reflect on several key areas. First, the exploration of additional case studies is necessary to further validate the findings and examine the contextualization of Asset Management (AM) in diverse scenarios. Expanding the scope of case studies will enhance the generalizability of the research outcomes. Additionally, future research should focus on streamlining research design and ensuring a higher degree of methodological consistency. This will not only facilitate comparability across studies but also increase the potential for deeper analytical insights.

Furthermore, the interaction between researchers and companies, particularly in the fields of business and technology, requires careful consideration. It is critical to clearly define and adhere to the role of the researcher, maintaining the position of observer, learner, and educator rather than crossing into the realm of consultancy. By avoiding engagement in consultancy activities, researchers can preserve the integrity of the academic inquiry and avoid encroaching on the consulting industry. Remaining firmly within the academic sphere and focusing on theorizing the outcomes of case studies ensures that significant contributions are made to the existing body of knowledge.

Lastly, even with the challenges of the participatory pragmatic approach for the case study, it was considered essential for this study. While the quantification of a business might be possible, as seen in the maturity assessment, when conducting a case study, and delving into the solution space, a quantitative approach might oversimplify the complexity. Thus, the case study aimed to represent the authentic reality of the case company, rather than overly simplifying their reality through a numerical representation.

5.3 Scientific contribution and significance

The exploration of agile within AM revealed a distinct gap in the literature, particularly regarding the integration of agile methodologies in this field. While there have been scattered discussions about the potential synergies between agile and AM (Baskarada, Gao and Koronios, 2006; Harris and Carapiet, 2006; Crombie, 2016; Ruitenburg, Braaksma and van Dongen, 2016), a comprehensive conceptual and practical framework has been notably absent. This dissertation addresses this gap by presenting both a novel conceptualization of agile processes and a framework for industrial agility tailored to the context of asset management.

The first publication in this dissertation presents a structured examination of agility by identifying three fundamental processes - knowledge, work, and control - as the foundational elements of agile operations. This paper advances the field by defining and interrelating these processes, demonstrating how they collectively enable agile governance, leadership, and management. The paper conceptualizes agility as a dynamic interplay between these three elements, where iterative decision-making, adaptive workflows, and decentralized control structures reinforce one another. By distilling these core processes, the study provides a clearer framework for understanding agility beyond specific industry applications, offering a foundation for further research into agile methodologies across diverse organizational contexts. While this study does not explicitly explore agility in asset management, its findings lay the groundwork for future research in this area. The structured approach to agile - emphasizing iterative work cycles, adaptive decision-making, and decentralized control - bears strong relevance to asset management, where long-term strategic planning must balance flexibility with structured governance. This connection suggests that integrating agile within asset management could enhance the ability to navigate uncertainties, optimize asset performance, and align operational strategies with evolving organizational needs.

The second publication extends this foundation by introducing industrial agility as a concept that bridges the gap between agile methodologies and asset management in industrial contexts. Unlike traditional notions of manufacturing agility, which often focus on operational efficiency in production environments, industrial agility emphasizes the adaptability of asset management systems within broader industrial ecosystems. This conceptualization is crucial as it incorporates strategic decision-making, risk management, and asset lifecycle considerations, aligning them with the principles of agility. The research also presents a novel framework that contextualizes the relationships between engineering assets, industrial agility, and the industrial ecosystem, offering both a theoretical model and practical guidance for implementing agile principles in asset-intensive sectors. This framework positions industrial agility not merely as an operational tool, but as a critical enabler of strategic responsiveness, helping organizations better manage disruptions and optimize asset performance. The value of these contributions lies not only in the novelty of the frameworks proposed but also in their practical applicability and the implications for future research. The framework for industrial agility can guide industry practitioners in designing more agile asset management strategies that enhance both operational efficiency and strategic flexibility. By incorporating agility into asset management, organizations can improve their decision-making speed, risk mitigation, and alignment with broader organizational goals. From a research perspective, this dissertation lays the groundwork for future studies exploring how industrial agility influences asset performance, maintenance strategies, and the integration of digital technologies in asset management. The frameworks introduced provide a useful starting point for empirical investigations into how agility affects the decision-making processes in asset-intensive industries.

Chapter 3 of this dissertation investigates digitalization from both theoretical and practical perspectives, identifying two primary contributions. The contribution of the first publication in chapter 3 is the development of a framework that maps and correlates data maturity with maintenance strategies in a structured 3×3 grid. This artifact serves as a decision-support tool designed to help organizations balance technological opportunities with enterprise capabilities in digitalization efforts. The framework was developed through empirical case studies across four companies and refined through literature on digitalization, maturity models, and maintenance management. By structuring digitalization maturity in relation to asset maintenance, the model provides a practical mechanism for organizations to assess their current state and align their digital transformation efforts with maintenance and condition monitoring strategies. Evidence of its applicability is drawn from the industry cases, where the framework helped to identify gaps between digital ambitions and operational realities, offering structured guidance for digital adoption in asset maintenance management.

The contribution of the second publication in chapter 3, is an empirical assessment of the digitalization maturity of the Danish industrial sector in relation to asset and maintenance management. While numerous maturity models exist in the literature, there is limited research on their real-world application and the actual digitalization status of industrial organizations within the field of asset and maintenance management in Denmark. This study addresses that gap by evaluating how digital maturity manifests in practice and identifying discrepancies between theoretical digitalization potential and the realities of industrial implementation. The findings suggest that, despite enthusiasm for digital transformation, many organizations face challenges in aligning digital investments with asset management needs. The perspectives gained from this assessment highlight the necessity for a balanced digitalization approach - one that considers both the opportunities and constraints of emerging technologies. This nuanced understanding contributes to existing literature (Stentoft, Rajkumar and Madsen, 2017; Brasen and Tambo, 2023; Maletič, Grabowska and Maletič, 2023) by emphasizing the role of organizational context in shaping digitalization strategies, reinforcing the need for pragmatic and adaptive implementation frameworks in asset management.

Chapter 4 centers on the development of a decision-support artifact that integrates agile methodologies and digitalization into an asset management-relevant activity. This artifact, designed as a framework for risk-based planning and prioritization, was specifically developed for the case company but is grounded in broader principles that extend beyond the specific application. The novelty of this framework lies in its structured transformation of experience-based planning methods into a data-driven decision-making approach, leveraging risk assessment techniques to enhance alignment with established asset management principles. By incorporating iterative feedback loops from agile methodologies and real-time data from digitalization efforts, the framework ensures that asset-related decision-making is both adaptive and evidence-based, ultimately increasing compliance with AM standards.

This research is among the first (Crombie, 2016; Maletič et al., 2023; Harris and Carapiet, 2006) to conceptualize a structured framework that explicitly integrates agile and digitalization within an AM context. While prior studies discuss digitalization in AM or propose agile as a flexible management approach, this artifact uniquely combines both elements in a practical intervention. The value of this approach is demonstrated through its ability to shift traditional AM processes from static, experience-driven prioritization to a more dynamic, data-informed methodology, improving responsiveness to operational uncertainties and strategic alignment with business objectives. Unlike existing conceptualizations that treat agility and digitalization as separate enablers of AM, this research highlights their synergistic potential, showing how they can be mutually reinforcing in supporting risk-based decision-making, compliance with AM frameworks, and enhanced operational performance. By answering RQ3, this research demonstrates how an applied EAM intervention that builds on agility and digitalization can advance operational goals and objectives while ensuring stronger compliance with AM principles. The proposed framework offers both practical value for industry practitioners and theoretical contributions to AM research, providing a scalable and adaptable approach to integrating agile and digitalization into asset management processes.

Finally, this research is characterized by its applied pragmatic approach, which integrates empirical case study research with direct engagement with industry professionals through communities of practice in asset management. This approach aligns with American/Jamesian pragmatism, where truth is determined by the practical consequences and usefulness of ideas in real-world application (Bulleit, 2017). Rather than seeking a purely theoretical optimization of asset management methodologies, this research follows a satisficing approach (Bulleit, 2017), where solutions are developed to be "good enough" within the constraints of industrial reality - balancing theoretical insights with practical feasibility. While the combination of case studies and industry interaction is common in engineering research, this study stands out by explicitly linking these methods within an agility- and digitalization-focused asset management framework, an area where practical and theoretical integration remains underdeveloped. By grounding the research in both industry-driven challenges and academic discourse, this study provides a holistic perspective on asset management, offering insights that are both actionable for practitioners and meaningful for advancing academic understanding. This methodological approach ensures that the findings are not only theoretically sound but also pragmatically valuable, bridging the gap between academic theory and industrial application in asset management.

5.4 Implications for practice

The integration of EAM with agility and digitalization carries significant practical relevance across various industries, particularly those that manage complex and extensive asset portfolios, such as utilities, public transport, and infrastructure. The findings and artifacts proposed in this research offer tangible benefits that can directly impact the efficiency, compliance, and strategic alignment of organizations.

The research emphasizes the development of a set of asset management and agile artifacts that can help both large-scale projects and smaller activities adhering to certification and regulatory requirements. In practice, this means organizations can better manage their assets, reducing the risk of non-compliance and ensuring that all activities contribute to the overall operational goals. By maintaining strict compliance across all levels of operation, companies can avoid costly penalties and enhance their reputation in the market.

By integrating agile methodologies and digitalization, organizations gain access to real-time data and insights that are crucial for making informed decisions. The practical relevance here is clear: improved decision-making leads to better prioritization of resources, more effective risk management, and the ability to respond swiftly to changes in the market or operational environment. This directly impacts an organization's ability to maintain a competitive edge and achieve its strategic objectives.

The framework proposed in this research promotes operational efficiency by streamlining processes through digital tools and agile practices. For companies, this means reduced downtime, optimized maintenance schedules, and a more efficient use of resources. In a practical sense, this can lead to significant cost savings, improved asset lifespan, and a more resilient operational structure capable of handling unforeseen challenges.

One of the key practical implications of this research is the ability to align asset management practices with broader organizational goals. By incorporating agility and digitalization, organizations can ensure that their asset management strategies are not just reactive but also strategically proactive. This alignment is crucial for companies looking to navigate the complexities of modern markets, where strategic goals must be supported by robust operational practices.

The practical relevance of integrating AM with agility and digitalization is evident in its ability to improve compliance, decision-making, operational efficiency, strategic alignment, technological adaptation, and scalability. These benefits are not just theoretical; they have direct, actionable implications for organizations looking to enhance their asset management practices and achieve long-term success in a competitive and rapidly evolving market.

5.5 Future research

Based on the findings and discussion of this dissertation, the following summarizes the potential avenues for future research topics:

- **Increase the amount of case studies:** Although the dissertation is grounded in a substantial in-depth case study, there is value in conducting additional case studies. Doing so could further the exploration of digitalization and agile integration in AM, solidifying robustness and validity. Further, pursuing other angles of integration comparatively to the case study done, will broaden the scope for deployment in relation to AM activities.

- **Refinement of the methodological approach:** For future case studies the recommendation is to develop a more systematic approach to executing these, across companies. Meaning that streamlining the research endeavors, i.e. interviews, problem gathering, solution development, etc., arguably enhancing the depth and research insights gained. Further, this potentially could increase the efficiency of the research conducted.
- **Investigate other industries:** While this research focused primarily on the utility industry, because of the case study, extending the research into other industries, specifically more traditional manufacturing companies could be enlightening. A study done within these parameters, could explore AM in a setting that is rarely explored and possibly determine why traditional manufacturing companies seem to neglect or not engage with the concept of AM.
- **Investigate smaller companies:** Mirroring the sentiment of the previous recommendation for a future research opportunity, investigating smaller companies, i.e. SMEs could provide a different perspective comparatively to this dissertation. One avenue of research could be to determine what resource constraint, whether monetary or manpower related, affect the ability to execute and perform AM, and whether agile and digitalization could enable easier access to AM as a management system.
- **Small scale AM intervention to large scale integration:** The developed artifact from the case study, while solving the posed problem and viable for the intended purpose, affects a relatively small part of the AM operations. While this is interesting, it stops short of determining whether a full-scale integration of agile and digitalization is viable in an asset management compliant organization. Thus, investigating this would be an interesting avenue to pursue. Future research should delve into how a larger scale integration could be accomplished, and whether the proposed argument for the benefits of integrating stands up to the scrutiny of the full-scale system integration.

5.6 Personal reflections

The following section is a self-reflection and is therefore, written in first-person.

The journey of investigating, developing and detailing this dissertation, through first developing theoretical baselines, having ongoing interactions and facilitation activities with communities of practice, and finally the case study, have been an immensely educational journey. At the start of this journey three years ago, the slightly naïve ambition was to develop an overarching framework for asset management, that through agile methodological approach would enable a one stop shop for implementing AM. However, throughout this journey it quickly became evident that would not be a possibility. The variety between companies and the subjective and arguably ambiguous nature of the guidelines in ISOs 5500x series, proved that such a framework likely never would be viable, and wholly too complex to pursue.

The dissertation has provided a significant number of opportunities and likewise responsibilities following these opportunities, both in the interactions with fellow researchers, practitioners in the field and companies that have invited me into their daily operations. Entering these interactions, especially the one with the case company as an unknown external factor, with no direct stake in the company, was challenging, but uniquely interesting. The challenge was inherently on the shoulders of myself as a researcher, as the way I approached the company had a direct influence on the success of the endeavor. Gaining trust, exploring different perspectives and ensuring good communication was critical, as the size of the company provided a wealth of different people and departments to interact with, each with different perspectives and cultures. The success of the case study rested on my ability as a researcher to sufficiently convince the case company that spending time and resources on me, would yield tangible benefits. With only one case study done in this dissertation, I am still learning this, and it is a skill that are critical to develop further when looking towards a future were convincing case companies to trust in my abilities as a researcher is imperative.

Throughout this project, I have become increasingly aware of the benefit's close interaction between the academic community and companies, brings to the knowledge base. Such a relation does provide interesting and valuable research, but just as important it significantly increased the interactions between the companies involved and the researcher involved, and by extension the university. A perfect example of this collaborative benefit, is that a participant in one of the communities of practice, showed interest in the study, and through that interaction became a significant sparring partner in the Ph.d project, and I for them in their AM certification efforts. However, it is a delicate balance, as obtaining academic insights while the industry partner obtain relevant and applicable results, is tough.

Another interesting and important observation for me at least, is the significant gap that seems to exist between the academic work being done currently and the reality of the companies working and living asset and maintenance management. While academia to great success is exploring avenues of digitalization through industry 4.0 and now 5.0, the industry I have interacted with through networking, company visits and case work are all playing catch up, and to a significant degree. Hence, the relevance of conducting grounded research that is applicable in practical operational settings, seems to arguably be more important than ever. Especially considering the increasing complexity in managing a company's assets to a sufficient degree, adhering to risks, opportunities, an aging workforce and assets, the list goes on. Conducting research that have immediate benefits for the practitioner and is academically grounded is thus highly relevant and interesting to me.

The journey of this dissertation has been immensely interesting and full of new knowledge. Initial perceptions and understandings of AM, agility and digitalization have continually been challenged and reformed, due to inputs and information obtained from practitioners, literature and academics in the fields. The complexities of asset management have sparked numerous reflections and learning moments. And, considering where I was, to where I am today, shows that this project has not just been one of academic exploration, but also a journey of professional and personal development and growth.

5.7 Conclusion

This Ph.d dissertation has answered the research questions presented in Section 1.2, through five published or submitted research papers. The project began with a parallel investigation of the theoretical and practical baseline of agile and digitalization, to determine the potential for integration into asset management. From the agile baseline, three distinct fundamental process of agile in relation to leadership, governance and management was determined, *knowledge, work* and *control processes*. Then a definition for industrial agility is proposed and an artifact that encapsulates this definition in relation to engineering assets and that the ecosystem within which they operate, was developed.
From the digitalization baseline the findings are likewise obtained from two separate publications. The first is the argument for and development of a 3x3 matrix that encapsulates data maturity and maintenance strategy. The proposed framework argues for different considerations related to decision-making on adjusting the needs concerning the operational performance and asset management, in relation to data and efficiency. The second is an analysis of a questionnaire conducted on a group of industry professionals, detailing the maturity level of these concerning digitalization within the scope of asset management, and detailing some indicators for digitalization within the same scope. The results of the questionnaire showed that the Danish industry, based on the available data, largely had a below average perception of their own digitalization maturity. Indicating that potential for improvement existed, across industries but particularly in the traditional manufacturing and logistics and infrastructure industries was there a below average result. Consequently, the maintenance service industry had a slightly higher result regarding their maturity. Further, the data showed that the general foundational perception of the maturity towards asset management and subsequently maintenance management, which had no relation to IT or system

integration, was average. Thus, potential for improvement at the foundational level a definite possibility, and likely to be a better investment than pursuing digitalization solutions to solve the foundational issues.

The final publication presented in this dissertation, answers the third research question, correlating and building upon the information gathered and artifacts created in the previous publications, either directly or indirectly. The single in-depth case study was conducted in a Transmission service operator (TSO), specifically focusing on asset management activities and the potential for improvement through strategic interventions. The case study was instrumental in arguing for the deliberate value that could be ascertained through an agile and digitalization integration into asset management activities. The artifact created provided a novel prioritization method, that rather than using experience primarily as a prioritization methodology, used risk a deciding factor. Agile incorporated implicitly to comply with the increasing demands and responsiveness to change that the portfolio was facing. Visualization of data and system integration of the proposed priority model was where digitalization is represented in the developed artifact.

In conclusion, this dissertation contributes to the understanding of asset management, agility and digitalization, by offering a novel framework for prioritization and visualization of the industrial ecosystem. But more importantly providing the perspective that agility and digitalization can enhance the asset management efforts of an organization. These insights provide a valuable perspective in an increasingly complex future, of manpower shortages and skill gaps. Thus, ensuring knowledge retention, efficiency and resistance to change from agile, correlated with the increases in data availability, enhanced decision-making and more efficient monitoring opportunities, from digitalization, asset management as a management methodology will benefit from integrating both.

6 References- chapter 1 to 5

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Appendix 1- Co-author statement – Section 2.1.

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Declaration of co-authorship[1] Date: 14/06/24

This declaration concerns the following article/manuscript:

Title:	The role of knowledge, control, and work processes within agility
Authors:	Lucas Peter Høj Brasen, and Torben Tambo

The article/manuscript is:
☒ Published, state full reference: Brasen, L. P. H. & Tambo, T., 8 nov. 2021, Proceedings of the 17th European Conference on Management, Leadership and Governance, ECMLG 2021. Academic Conferences and Publishing International Limited, s. 83-89 7 s. (European Conference on Management, Leadership & Governance).
☐ Accepted, state journal:
☐ Invited for revision, state journal:
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☐ In preparation

Date of the current version of the manuscript, if not published or accepted:

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A. Research idea: Identifying, developing, specifying, and formulating the overarching research question and aim.
B. Theory: Organizing theoretical perspectives, developing arguments and hypotheses, specifying theoretical model.
C. Research design: Developing and planning design for test or exploration of the research question.
D. Data collection: Preparing and organizing data collection, data collection, preparing data for analysis and storage.
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of this article/manuscript as follows:

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3 Major contribution
2 Equal contribution
1 Minor contribution
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Table 1. Individual contributions and signature of each co-author[1]

Author	Extent of contribution (4-0) per element (A.-F.)						Signature of the author[2]
	A. Research Idea	B. Theory	C. Research Design	D. Data Collection	E. Data Analysis	F. Writing	
Lucas Peter Høj Brasen	2	3	2	4	2	3	Lucas PH Brasen
Torben Tambo	2	1	2	0	2	1	

[1]More rows can be added for additional authors.
[2]All authors must confirm the declaration either by signature or email.

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Appendix 2 – Co-author statement – Section 2.2.

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Declaration of co-authorship[1] Date: 14/06/24

This declaration concerns the following article/manuscript:

Title:	On Defining Industrial Agility as a Strategic Capability for Competitive Performance of Engineering Assets: An Industrial Eco-systems Perspective
Authors:	Lucas Peter Høj Brasen, and Jayantha P. Liyanage

The article/manuscript is:
☒ Published, state full reference: Brasen, L. P. H. & Liyanage, J. P., 2022, IEEE International Conference on Industrial Engineering and Engineering Management, IEEM 2022. IEEE, s. 583-587 5 s.

- ☐ Accepted, state journal:
- ☐ Invited for revision, state journal:
- ☐ Submitted
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Lucas Peter Høj Brasen	2	2	2	3	2	3	Lucas PH Brasen
Jayantha P. Liyanage	2	2	2	1	2	1	[signature] 20/6/24

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Appendix 3 – Co-author statement – Section 3.1.

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Declaration of co-authorship[1] Date: 14/06/24

This declaration concerns the following article/manuscript:

Title:	Comparison between data maturity and maintenance strategy: A case study
Authors:	Lucas Peter Høj Brasen, Oliver Fuglsang Gross and Torben Tambo

The article/manuscript is:
☒ Published, state full reference: Høj Brasen, L. P., Groos, O. F., & Tambo, T. (2021). Comparison between data maturity and maintenance strategy: A case sutdy. Procedia CIRP, 104, 1918–1923. https://doi.org/10.1016/j.procir.2021.11.324[2]
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Lucas Peter Høj Brasen	2	2	2	2	2	2	Lucas PH Brasen
Oliver Fuglsang Gross	2	2	2	2	2	2	[illegible]
Torben Tambo	2	2	2	2	2	2	[illegible]

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Appendix 4 – Co-author statement – Section 3.2.

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Declaration of co-authorship[1] Date: 14/06/24

This declaration concerns the following article/manuscript:

Title:	The Exploration of Digitalization and Digitalization Indicators Within the Scope of Asset Management
Authors:	Lucas Peter Høj Brasen, and Torben Tambo

The article/manuscript is:
☒ Published, state full reference: Brasen, L. P. H. & Tambo, T., feb. 2023, 16th WCEAM Proceedings, 2022. Crespo Márquez, A., Gómez Fernández, J. F., González-Prida Díaz, V. & Amadi-Echendu, J. (red.). Springer, s. 312-322 11 s. (Lecture Notes in Mechanical Engineering).
☐ Accepted, state journal:
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Lucas Peter Høj Brasen	3	3	2	4	2	3	Lucas PH Brasen
Torben Tambo	1	1	2	0	2	1	Torben Tambo

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Appendix 5 – Co-author statement – Chapter 4.

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Declaration of co-authorship[1] Date: 12/08/24

This declaration concerns the following article/manuscript:

Title:	Mind your (green) business: The role of agility and risk in operational life-cycle projects in Transmission System Operators - between
Authors:	Lucas Peter Høj Brasen, and Torben Tambo

The article/manuscript is:
- ☐ Published, state full reference:
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- ☐ Invited for revision, state journal:
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N/A Not relevant or not applicable

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Torben Tambo	1	N/A	1	N/A	1	1	Torben Tambo

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