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Refining Planning Efficiency through Data and Process Management

- A Case Study at Siemens Energy

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Abstract

This master's thesis examines the maintenance planning process for gas turbines at Siemens Energy (SE), with a particular focus on the challenges and improvement potential associated with handling of late changes in the maintenance planning process. The study is motivated by the increasing complexity and growing demand for customization in the energy sector, which highlights the need for more dynamic and responsive solutions to handling unforeseen events.

The study aims to answer how late changes affect the maintenance planning process, identify the most time-consuming parts of the process when late changes occur, and propose improvements in process and data management. To answer these questions several methods were used, including a literature study, interview study, process mapping, PFMEA and quantitative analysis of technical request data.

The empirical study investigates the specific process of maintenance planning at SE and reveals that late changes in maintenance planning create a domino effect of inefficiencies, not only disrupting operations but also placing significant strain on personnel. The analysis reveals that the most significant bottlenecks are risk analysis procedures, interdepartmental communication, and decision-making related to schedule extensions.

Based on these findings, the thesis proposes a set of actionable improvements. Short-term recommendations include standardized responsibility allocation, enhanced data accessibility for application engineers and more concise technical request protocols. Long-term strategies focus on co-creation between departments, the integration of maintenance data into unified project management platforms, digitization and standardization of historical records, and the automation of risk analysis using AI.

The study concludes that addressing these process and data management challenges can significantly reduce lead times, improve operational efficiency, and enhance the reliability of maintenance planning, not only at SE but it can also be adapted to maintenance planning in various industries and operational processes. The results highlight the importance of aligning technological advancements with organizational processes.

Acknowledgement

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We would like to extend our sincere appreciation to our supervisor at Siemens Energy, Pontus Slottner, whose ongoing support and valuable insights into both the gas turbine industry and Siemens Energy as an organization have been instrumental throughout this project. Our gratitude also goes to all the Siemens Energy employees who participated in the study and generously took the time to share their experiences and perspectives with us. Your engagement and openness have greatly helped this study progress.

Finally, we wish to thank our academic supervisor at Linköping University, Peter Cronemyr, for his guidance and constructive feedback, which have been crucial in shaping the quality of this thesis. We are also grateful to our opponents, Viktoria Berglund and Samuel Andersson, for their thoughtful comments and advice throughout the spring, helping us to further develop and refine our work.

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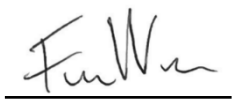

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Glossary

Term	Definition
SE	Siemens Energy
AE	Application Engineer
SAP	An enterprise business system used by SE
PLM	A product lifecycle management system used by SE
AED	Application Engineer Dashboard, a system used by SE
EOH	Equivalent Operating Hours
EOC	Equivalent Operating Cycles
PM	Project Manager
CCM	Customer Contract Manager
CPM	Commercial Project Manager
OPM	Overhaul Project Manager
LPM	Logistics Project Manager
SM	Sales Manager
LTP	Long-Term Plan

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1. Introduction

The following chapter outlines the potential for improvement in the maintenance planning process at an industrial company working with gas turbines. It presents the background history, challenges and improvement potential of this process. Lastly, the history and current situation at the industrial company is briefly described.

1.1 Background

The energy sector has undergone significant transformations over the past few decades, driven by technological advancements, regulatory changes, and evolving market demands. According to the International Energy Agency (2020), maintenance planning, a critical component of operational efficiency and reliability, has also evolved in response to these changes. Traditionally, maintenance planning in the energy sector, particularly for complex machinery like gas turbines, was predominantly preventive and scheduled based on fixed intervals (Smith, 2011). However, Hoffmann and Lasch (2025) explains that the increasing complexity of energy systems and the need for higher operational flexibility have driven a shift towards more dynamic and responsive maintenance strategies.

Gas turbines are essential in modern energy systems due to their efficiency, reliability, and ability to quickly ramp up and down in response to demand fluctuations (Boyce, 2011). Saravanamuttoo, Rogers, and Cohen (2001) highlight that they are used in various applications, from power generation to mechanical drive systems in industries. The performance and reliability of gas turbines are important aspects for ensuring uninterrupted energy supply and operational efficiency (Saravanamuttoo, Rogers, & Cohen, 2001). Consequently, effective maintenance planning for gas turbines is essential to maximize their lifespan, minimize downtime, and ensure optimal performance (Boyce, 2011). Therefore, efficiency in this context refers to the ability to achieve maximum productivity with minimal waste. It involves optimizing the usage of resources, such as time, personnel, and materials, to ensure that maintenance activities are carried out with the smallest amount of resources necessary to achieve the desired result.

Despite advancements in technology, maintenance planning for gas turbines presents several challenges. Hoffmann and Lasch (2025) notes that these include the need to balance preventive maintenance with the flexibility to address unexpected issues, managing the complexity of the machinery, and ensuring that maintenance activities do not disrupt operations. Additionally, Smith (2011) points out that the increasing demand for customized solutions from customers adds another layer of complexity to maintenance planning.

1.2 Problem Description

The current maintenance planning processes face several challenges, particularly in adapting to changes in customer operational needs, technological advancements and an increasing scale of operation (Bring & Lindström, 2023). These challenges require adaptation to new combinations of operating conditions, fuels, and maintenance strategies, a willingness to improve and a higher degree of flexibility in maintenance planning.

The problem mainly concerns the ability to manage late changes in maintenance planning. These late changes typically occur about six months before inspection. They lead to disruptions, inefficiencies, and increased resource expenditure, making it more difficult to maintain optimal performance and reliability. Therefore, existing processes for maintenance planning are not adequate in handling late changes.

Given the limited prior research on handling late changes within maintenance planning, this study will also explore theoretical approaches from logistics, supply chain management, and project management to develop a comprehensive framework for managing late changes.

1.3 Case of Siemens Energy

Siemens Energy (SE), a global leader in the energy sector, is at the forefront of addressing challenges described in Chapter 1.1. SE specializes in energy solutions, offering products like compressors, gas turbines, generators, and heat pumps (Siemens Energy, 2024). Their industrial gas turbines are used for generating electricity and powering mechanical drives, making them ideal for a multitude of different industry purposes due to their compact design (Siemens Energy, 2025b).

SE has a long history, starting in 1866, and became an independent entity in 2020 (Siemens Energy, 2025c). Turbine production in Finspång began in 1913, and Siemens acquired the business in 2003 (Siemens, 2025). The company operates in three main areas: Gas Services, Grid Technologies, and Industry Transformation (Siemens Energy, 2024).

Gas turbines are categorized by output: small (0-15MW), medium (15-100MW), and heavy-duty (100-600MW) (Siemens Energy, 2024). The medium-sized gas turbines from Finspång are versatile and commonly used for electricity generation, compressor drive and as backup electricity systems (Siemens Energy, 2024).

SE is focused on improving their maintenance planning processes to meet the growing market demands for flexibility and customer customization (Siemens Energy, 2025b). The application engineer (AE) plays a vital role in this process, being responsible for adapting maintenance to meet technical customer requirements (Bring & Lindström, 2023). SE seeks to improve its understanding of how processes and management of data can be developed to better manage deviations and enhance maintenance planning (Siemens Energy, 2025b).

Effective data management is essential for handling late changes in maintenance planning at SE (Siemens Energy, 2025a). The study aims to explore how key information is distributed among key participants involved. Currently, there is a variety of programs where this data of information is stored, and it can be difficult to get a hold of the information (Rincon Franco, 2024). The AE is a central figure in this process, but varying levels of experience may influence how work is conducted among different engineers (Rincon Franco, 2024). Therefore, the study will also provide a perspective on how varying levels of experience impact the flow of information and how the AEs carry out their tasks.

Rincon Franco (2024) mentions the Application Engineer Dashboard (AED), which is an online tool developed by SE that helps plan and execute maintenance tasks for turbomachinery. AEs use it to document technical requirements and tailor services to customer needs, technical challenges, and product history. It simplifies recording maintenance activities, suggests necessary tools, and standardizes the documentation of materials and instruments for easy ordering. Additionally, it supports modernization and upgrades of the turbines.

This study is not only relevant to SE but also holds broader implications for the energy sector and industries relying on complex machinery. By addressing the challenges of late changes in maintenance planning, the findings can be generalized to improve maintenance strategies across various contexts. The insights gained can help other companies enhance their maintenance processes, optimize data sharing, and better manage unforeseen disruptions and/or deviations, ultimately leading to increased operational efficiency and reliability.

2. Task Specification

The following chapter specifies the purpose of the study, and the research questions the study aims to answer. It also presents the scope within which the questions are to be asked, and the delimitations and limitations made in this study.

2.1 Purpose of the Study

The purpose of the study is to describe and analyze a maintenance planning process and how it can be improved. The study specifically aims to provide clarity regarding whether there are combinations of improvements regarding process and data management which have an impact on the ability to handle late or unforeseen changes in maintenance planning.

2.1.1 Research Questions

- *RQ1: How is the maintenance planning process affected by late changes?*

- *RQ2: What parts of the maintenance planning process are most time-consuming to handle when there are late changes in maintenance planning?*

- *RQ3: How could the handling of late changes in maintenance planning be improved, with regard to data and process management?*

2.2 Scope of the Study

The scope of this study includes an in-depth examination of the impact of late changes on the maintenance planning process. It will investigate the process of handling a late change and which the decision-points are. Furthermore, it will answer which of them are the most demanding, and how they can be improved. By doing so, the study aims to provide a comprehensive understanding of the challenges associated with late changes.

Furthermore, the study will identify the most common causes of late changes in maintenance planning and evaluate which parts of the process are not functioning optimally. It will propose improvements to enhance data management and availability, and improve the process, with the goal of reducing the time required to update the scope of maintenance projects.

In Figure 1 the processes related to the scope are visualized, displaying the focus within maintenance planning on handling late or unforeseen changes. By addressing these issues, the study aims to offer actionable recommendations for streamlining maintenance planning through improvements in data and process management.

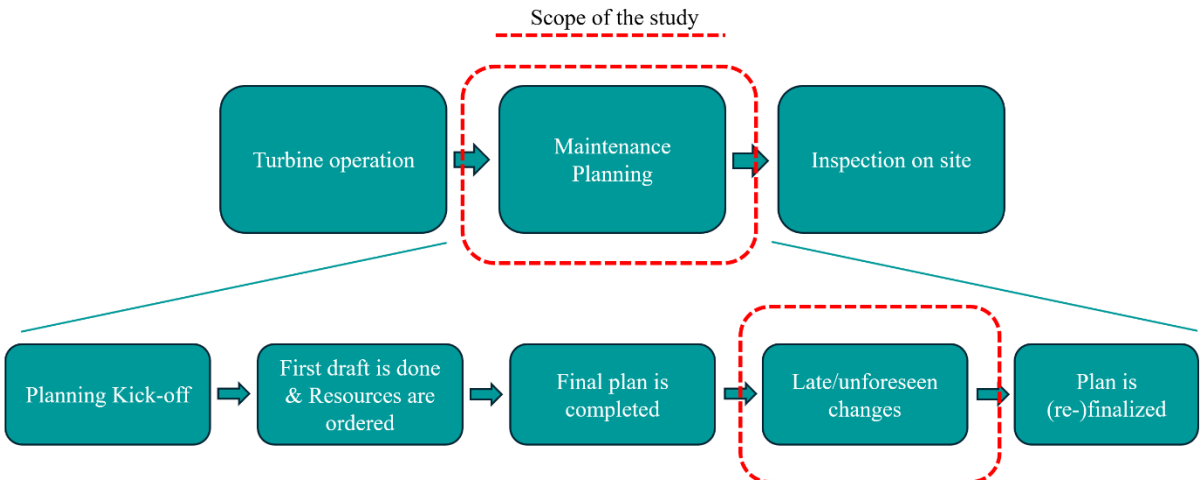

Figure 1 - Scope of the study

2.2.1 Delimitations & Limitations of the Scope

Several limitations have been established to this study by the authors. These limitations arise either from company directives or from the authors' assessment of what can be realistically achieved during the study.

Delimitations

- The study has a primary focus on the maintenance planning of the SGT 600 gas turbine. Different gas turbine fleets have varying maintenance schedules, which can lead to misunderstandings when interviewing personnel working with different models. The SGT 600, being an older model, has undergone numerous repairs and upgrades, making it challenging to adhere to a standard maintenance plan. This characteristic aligns with the study's objectives.

- The study is delimited to planned inspections which are contracted by LTP, therefore excluding one-off inspections. The main reason for this is that one-off inspections often vary between case to case much more than those that are bound by a LTP, and therefore they are less relevant for this study.

- The study is delimited to the handling of late changes in the planning stage, thereby excluding changes made close to the time of the inspection. This is because changes made within this short timeframe shift from being planned adjustments to reactive operational decisions, which are outside the focus of this investigation.

- The study mainly focuses on the role and responsibilities of the AE in maintenance planning. There are multiple other actors, namely the CPM, CCM, LPM, OPM and SM, which all have a role in maintenance planning, but these will not be explicitly discussed.

Limitations

- Practical implementation of improvements will not be carried out. Instead, the study will focus on identifying and recommending potential areas for improvement.

2.2.2 Continuation of Previous Study

A previous master's thesis addressed this topic with a scope on the overall maintenance strategy at SE. The study "Reduction of time allocation in maintenance planning - A Case Study at Siemens Energy AB", conducted by Bring and Lindström (2023) from the Division of Logistics and Quality Management at Linköping University, highlighted the need for further investigation. One key suggestion was to prevent late changes, defined as those ordered less than six months before the scheduled maintenance. This topic has been discussed at Siemens following their presentation, but it was determined that late changes often are unavoidable (Bring & Lindström, 2023). Siemens Energy (2025b) is committed to finding the best ways to manage late changes to minimize their impact on both AEs and customers.

This study partially aims to build on the findings of the previous research by focusing specifically on the management of late changes in maintenance planning for gas turbines. Bring and Lindström (2023) suggest that there are various "late change" scenarios that require different strategies for effective handling. Additionally, there is a need to refine the previously developed process map, as the current version does not in detail describe the action-steps after a late change has been requested (Bring & Lindström, 2023).

3. Methodology & Method Theory

The following chapter explains the methodology which is used in this study. It describes the steps taken to address the research questions and the purpose of the study. It begins with an overview of the study's structure, followed by an in-depth explanation of each phase. Lastly, the chapter concludes with a discussion on the study's credibility and ethical considerations.

3.1 Breakdown of the Methodology

The workflow adopted an explorative approach, allowing flexibility to investigate the impact of late changes in maintenance planning and data availability. This approach helped the study to focus on emerging insights in a complex subject. More information on the explorative approach is found in Chapter 3.2.

The study began with a general gathering of information and knowledge on the area, with the purpose of establishing a context to the situation and problem at SE. This was mainly acquired through meetings and document reviews. A literature study followed to provide a theoretical foundation.

An interview study identified the effects of late changes, process steps and critical-to-quality (CTQ) factors relevant to further analysis. Process mapping provided the foundation for overviewing the process, allowing for further analysis of process steps. Data gathering via the CTQ factors then ensured sufficient empirical evidence for evaluation. Data analysis focused on analyzing data connected to demanding process steps, providing further insight and evidence into the degree of complexity. Using process failure mode and effect analysis (PFMEA), it was made clear how failure of executing process steps affect the process. The impact-effort matrix was then used to determine what areas to improve. Together with key personnel at SE, improvements were brainstormed and evaluated in regard to feasibility.

The workflow concluded with synthesizing findings and presenting key insights, ensuring a structured yet adaptable examination of maintenance planning and challenges related to late changes. The methodology is illustrated in Figure 2.

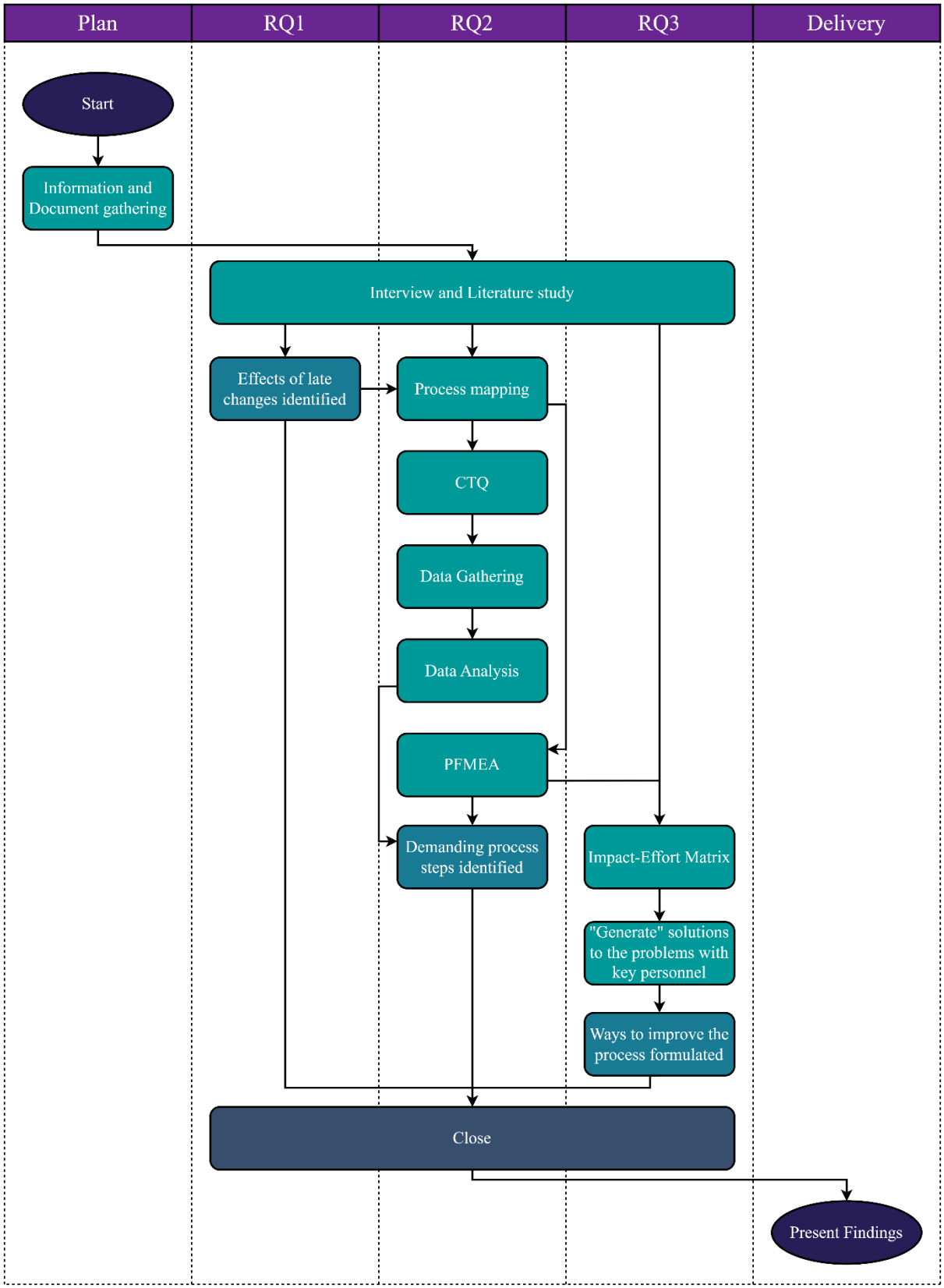

Figure 2 - Flowchart of Method

3.2 Explorative Study

This study aims to investigate how existing knowledge can be used to improve processes and data management in maintenance planning. Rather than generating new insights in a specific research domain, the focus was on applying established research. Consequently, the study falls under the category of explorative research, as defined by Saunders, Lewis, and Thornhill (2019) and further explained in Section 3.2.1. The study is classified as explorative based on several key aspects: limited prior research on handling late changes within maintenance planning, the aim to explore improvements in process and data management, and the goal to provide a clearer picture of the challenges faced in maintenance planning, particularly regarding late changes. This aligns with the explorative nature of the research, which is often conducted in the early stages of a research project to gather insights and inform further studies (Horváth, 2016).

3.2.1 Theory - Type of Study

Tcherni-Buzzeo and Pyrczak (2024) explains that the type of study selected for specific research is often determined by the existing knowledge within the field. Different studies have distinct purposes; some are designed to generate new insights, while others aim to apply existing research to specific problems. The current level of understanding in a field can influence the choice of study, as it is challenging to address specific issues without a foundational knowledge base. According to Saunders, Lewis, and Thornhill (2019), studies can be categorized into several types: explorative, descriptive, explanatory, and evaluative.

- **Descriptive Studies:**
  Used when there is some foundational knowledge, this type of study focuses on detailing the characteristics and relationships within the field without explaining the reasons behind them.

- **Explanatory Studies:**
  Aimed at providing a deeper understanding, this type of study seeks to describe and explain the relationships within the field, often involving hypothesis testing.

- **Evaluative Studies:**
  When there is substantial knowledge available, this type of study assesses the effectiveness of existing practices and provides recommendations based on this evaluation.

- **Explorative Studies:**
  These are conducted when there is limited knowledge in the field, with the goal of gaining a basic understanding of the subject. They help in formulating hypotheses and understanding the problem more clearly.

An explorative approach to research is particularly beneficial for this study as it allows for a flexible and adaptive investigation into the subject of maintenance planning. This approach enables researchers to look deeper into new insights and adjust their focus as new information emerges (Saunders, Lewis, & Thornhill, 2019).

The flexibility of an explorative approach allows the study to handle unexpected findings and new trends (Tcherni-Buzzeo & Pyrczak, 2024), ensuring the research remains relevant and comprehensive. As new data is collected and analyzed, researchers can refine their ideas and explore additional factors that may influence the outcomes. This is particularly important in a field where the interaction between various factors such as technological advancements, human decision-making processes, and organizational constraints can significantly impact the effectiveness in operations.

3.3 Information & Document Gathering

The process of gathering information and relevant documents for this study was largely conducted through close collaboration with the staff at SE. The personnel at SE provided insights by guiding this study, providing information, data and documents.

SE provided documents such as process maps, powerpoint presentations and mechanical records, which were highly valuable in the study. A specific contribution came from an AE Manager, who directed the authors of this report to a Systems Architect within the organization. This Systems Architect provided a data flow map, illustrating the interactions between different software programs used in the role of an AE. This map served as a foundational reference for understanding how data moves between applications and how different tools contribute to the overall workflow.

Furthermore, SE staff provided detailed explanations of the maintenance planning processes, shedding light on how scheduling, resource allocation, and preventive maintenance strategies are implemented. Additionally, technical aspects related to gas turbines were thoroughly explained, providing the technical knowledge required for understanding how the maintenance process is planned in a concrete way.

To build upon existing research, the supervisors for this master's thesis played a large role in providing previous master's theses as guides for this study. SE supplied a previous master's thesis from 2023, which served as a foundation for this study. This document provided essential background information, methodologies, and findings that were highly relevant. In addition, the academic supervisor provided another master's thesis, which was particularly relevant for understanding a specific software program, the AED.

3.4 Literature Study

A literature study was conducted to build a theoretical framework and contextualize the findings. This process involved analyzing scientific articles related to maintenance planning for gas turbines, with a specific emphasis on the role of process and data management, and if possible also late changes. The review utilized databases such as Scopus and Google Scholar. Common search terms, often combined, included "Gas Turbine", "Project Replanning", "Planning under Uncertainty", "Maintenance Planning", "Data Management", "Project Management" and "Process Mapping". To prioritize recent advancements, the search was limited to studies published from 2010 onwards, except in areas where more recent research was unavailable, in which case older studies were included due to their continued relevance. The theory supporting the methodology of a literature study is described in Section 3.4.1.

3.4.1 Theory - Literature Study

Conducting a literature review is an important step in gaining a thorough understanding of existing knowledge in a research area. According to Säfsten and Gustavsson (2019), a well-executed literature review should be guided by clear objectives to ensure relevance and reliability. This involves defining the purpose, refining search criteria, and critically evaluating the sources included.

The literature review can utilize a combined approach, integrating both systematic and iterative methods. Nyberg and Tidström (2013) describe chain searching as a useful method for identifying sources through references cited in prior research. This approach can be particularly useful for exploring foundational studies and tracing the development of key concepts over time. Additionally, the review process can benefit from guidelines as presented by Friberg (2022) on source selection. Friberg (2022) advocate for an initial screening of titles and abstracts, followed by a more detailed evaluation of full texts.

To complement the chain search, systematic search strategies can be employed, inspired by practices recommended by Säfsten and Gustavsson (2019). This involves defining search strings, such as variations of core topics, and using Boolean operators (i.e., AND, OR, NOT) to structure queries. These searches can be applied across multiple databases to capture diverse perspectives. Special attention can be paid to refining keywords during the process, as recommended by Nyberg and Tidström (2013), to enhance the precision of search results.

By blending structured methodologies with iterative adjustments, the review process can be flexible yet comprehensive, ensuring that the final selection of sources is both relevant and comprehensive. This theoretical foundation provides valuable context for addressing the research objectives and integrating insights into the study.

3.5 Interview Study

To collect qualitative information, interviews were conducted. The interviews are found in Appendix A - Interviews and a summation of all interviews held can be seen in Table A.1. The qualitative quality of interviews was used as it offers in-depth insights into the distribution of data within the maintenance process. For this study, a series of interviews were conducted where each set of interviews had a different approach. The theory supporting the methodology of interview study is described in Section 3.5.5.

3.5.1 First Set (A.1)

The first set of interviews was unstructured and open-ended, focused on gaining initial insight into what is relevant for the scope of this study. This also included gaining background knowledge, assisting in what themes to explore for the second set of interviews.

Participant selection was based on recommendations from the supervisors of this study. As the AE is central to the scope of this study, three out of four participants were AEs. The AEs were all rather experienced, therefore providing foundational knowledge within the area and insights guiding the study forward. The non-AE interviewee was an experienced System Architect that provided considerable information regarding data flow between different software systems. This contribution was important for the progress of the study as it quickly provided an overview, which would have been harder to acquire solely through interviews.

Preparation was done by deciding on the purpose for each interview, as well as formulating a few questions, as seen in Appendix A.1. As the interviews were intended to be unstructured, the questions were loosely formulated and only used as a guide if the flow of conversation subsided.

Documentation was done by taking notes and recording the interviews. The recordings were further analyzed to document information which was not noted during the actual interview. Some questions, as seen in Appendix A.1, were formulated after the interview, to structure topics brought up which were not addressed by the prepared questions.

3.5.2 Second Set (A.2)

The second set of interviews was conducted in a semi-structured format, guided by a series of predetermined questions that were based off the questions asked in the initial interviews. This format was deemed the most suitable for multiple interviews with a common purpose. Furthermore, the authors felt that during the first set, the unstructured approach had the drawback in that interviewees often spent much time on describing parts that may not be relevant, which would be less suited for the second set. The structure of these interviews is further detailed in Appendix A.2.

For this set, the six participants were exclusively AEs, allowing for a focused and in-depth exploration of how late changes in maintenance planning, as well as variations in data availability, influence and impact the overall maintenance planning process.

An interesting aspect was that the second set of interviewees had varying levels of experience in the AE role and at SE. This range of experience provided diverse perspectives on the issues within the maintenance planning process, offering broader and nuanced comprehension.

The preparation for this set was informed by insights gained from the first set of interviews, which highlighted certain themes for further investigation. As a result, several questions resembled those from the initial interviews. However, the first set of interviews indicated that the questions asked were too loosely formulated. Certain questions of the first set were asked with the purpose of providing some insight into the research questions, but the answers often deviated from what information was desirable in that regard, which pointed to the complexity of the themes discussed. Therefore, efforts were made to ask highly specific and well formulated questions, guiding the conversation to topics which provided highly relevant information. This was partially done by trying to immerse the interviewee in a specific scenario where late changes to the maintenance plan occur due to additional sales, for example.

The questions were formulated to find relevant information regarding the research questions. A prerequisite for answering *RQ1* was finding out what causes there were for late changes in the maintenance planning process, which involved discussions with the supervisor at SE and Senior AEs. The first question of the interview was to ask the AE to rank the causes that had been identified. This also meant asking if they thought there were causes that had been missed in identifying recurring causes of late changes.

Furthermore, the purpose of the first question was to find out information about *RQ2*. By rating causes for late changes, the interviewees would provide insight into what problems are the most time-consuming to solve. The second question was aimed at identifying how late changes affect the process (*RQ1*), by asking how the AE handles late changes, step by step. Their answers were further evaluated during process mapping. The remaining questions were aimed at exploring problems that could be addressed for *RQ3*.

Documentation was carried out in the same manner as before, involving both recordings and note-taking. The questions and answers were compiled into one document after all individual interviews had been documented, consolidating all information, as can be seen in Appendix A.2. The reasoning behind consolidating all interviews in this format was that the interviewees' answers were usually quite similar, so consolidating them in one document would ease analysis and documentation.

A type of coding was used in the analysis of the first question of this set. The hierarchical rating of different categories relative to each other allowed for them to be quantitively compared. Each cause for late change was seen as a code and given a numerical value, from 1 to 6, for how demanding the cause is to solve, where a higher number is more demanding. By calculating the average number for each cause, the causes could be rated by their individual average values.

3.5.3 Third Set (A.3)

The third set of interviews, like the second set, consisted of semi-structured interviews, but with the specific purpose of gaining additional perspectives on *RQ1*. The semi-structured format was kept in the third set because of the similarities to, and successful format of, the second set. By the time the third set was conducted, the process for handling late changes was being mapped, and this set provided valuable insights for continuing the work.

This set consisted of interviews of two PMs. The reason for interviewing the PMs was that they have a broad overview of the process. At the time of the third set this input was used to validate the process mapping to ensure it was accurate and had proper grounding in the organization. Similarly to the second set, the third set had varying levels of experience of the interviewees, but now for the PM role. This resulted in contrasting inputs, offering a broader and nuanced perspective.

The preparation for these interviews involved carefully formulating the right questions. Previous interviews had emphasized the importance of being specific to guide the answers toward relevant and useful insights. Given the focus of this set, the questions were designed to gather information on decision points and activities, similarly to the second question of the second set of interviews in Appendix A.2. The documentation for this set followed the same structure as the previous sets, as can be seen in Appendix A.3.

3.5.4 Fourth Set (A.4)

The fourth set of interviews was specifically aimed at brainstorming improvement suggestions related to RQ3. To allow participants to express their thoughts freely, these interviews were conducted one on one, in an open-ended and unstructured format. This approach was chosen to encourage spontaneous discussion and to capture a wide range of perspectives that might not emerge in a more structured setting.

Six participants were selected for these interviews, representing different roles within the organization. The set included mainly AEs and technical requests handlers. This variety was intentional, as it was important to gather input from individuals with different experiences and viewpoints of the improvement areas which had been determined. This ensured that the suggestions for improvement would be comprehensive and well-rounded for all improvement areas (see Chapter 7). As it was deemed that certain roles had more expertise regarding certain areas, the discussions were adapted accordingly. For example, brainstorming improvements regarding data management were mainly done with AEs.

In preparation for the interviews, a set of leading questions was developed, based on discussions from previous interviews. These questions were not meant to dictate the direction of the conversation, but rather to serve as prompts in case the discussion stalled or did not flow naturally. The questions were formulated from initial ideas that needed be further developed, leading to further discussions. Documentation of this set was mainly done by taking notes, which in turn were developed into a list (see Appendix A.4), and then developed into detailed suggestions. Overall, this method managed to collect meaningful feedback for RQ3.

3.5.5 Theory - Interview Study

The interview method, rooted in social sciences, remains valuable due to its flexibility according to Vuori (2017). In organizational research, interviews are particularly effective for exploring sensitive issues and understanding cognition and emotion with tact. While observation shows actions, interviews explore mental states (Vuori, 2017). The adaptability of interviews allows researchers to tailor questions to specific contexts, offering deep insights into thought patterns. However, interviews can lack structure, complicating reliability and validity. Findings may also be affected by participants' biases or subconscious influences.

Interviews involve asking questions that range from structured (precise and ordered) to unstructured (open-ended and flexible). According to Vuori (2017), structured interviews are ideal for quantification and theory testing and rely on predefined categories for consistency. On the other hand, unstructured interviews excel at exploring themes deeply by letting participants guide the discussion, allowing participants to freely share thoughts (Vuori, 2017). Semi-structured interviews combine the strengths of both structured and unstructured interviews but may lack the focus of either extreme.

Preparation is important for successful interviews (Vuori, 2017). Understanding the interviewee's background and context helps build rapport and ask focused questions. Addressing formal aspects, like explaining the interview's purpose, securing consent, and promising anonymity, creates a comfortable environment. Including these details in early contact ensures the interview starts informally and smoothly.

Lastly, interviewee selection is a highly important aspect of the interview process. According to Robinson (2014), purposeful sampling is often used in qualitative research to select participants who can provide rich, relevant, and diverse data. This involves identifying individuals who have specific knowledge, experience, or perspectives that are pertinent to the research questions. Robinson (2014) emphasizes the importance of considering the interviewee's role, expertise, and potential contribution to the study's objectives. By strategically selecting interviewees, researchers can ensure that the data collected is comprehensive and insightful, thereby enhancing the overall quality and relevance of the research findings.

3.6 Process Mapping

To address *RQ2*, process mapping was used to provide a clear overview of all aspects in the process of handling a late change in maintenance planning. This method was also useful in answering *RQ3*, as it helped link lead times and improvement areas to specific activities or decision points. The goal was to create a process map focused on the AE's decision points, identifying potential bottlenecks related to lead times or data flow, specifically when late changes occur in the maintenance plan.

Development of the process map required extensive information, as it needed to cover all possible approaches for handling recurring causes of late changes. Information for the process map was mainly gathered during the interviews, as described in Chapter 3.5. By closely examining the answers to how the AE handles late changes, a draft of the process map was made, outlining activities and decision points. Given the complexity of the process, multiple iterations of the process map were made, refining both clarity and accuracy while preserving its intricate nature.

After the first draft was completed, the authors of this report collaborated with SE to continuously refine the process map. This included the insights from the third set of interviews, as described in Section 3.5.3. Furthermore, SE provided additional scenarios and decision points, which were used to create additional branches and add more detail to the map.

Once the process map was considered to adequately describe the process, it was sent out for validation to ensure it had real grounding within the organization. The map was distributed to three individuals at SE with extensive experience of the process, along with a set of five questions for them to answer. The outcome was a process map that emphasized decision points and the distribution of responsibilities, providing a solid foundation for further analysis and ensuring that subsequent evaluations of the process would yield meaningful insights which have real grounding in the organization.

3.6.1 Theory - Process Mapping

Process mapping is a visual technique used to illustrate the steps and sequence of activities within a specific process. It serves as a tool for understanding, analyzing, and improving workflows, providing clarity about how tasks and decisions flow from one stage to the next, as stated by Heher and Chen (2017). Typically presented as flowcharts, process maps can vary in complexity, from simple diagrams to detailed, multi-layered representations. Process maps are usually illustrated using different figures (Heher & Chen, 2017), as can be seen in Figure 3.

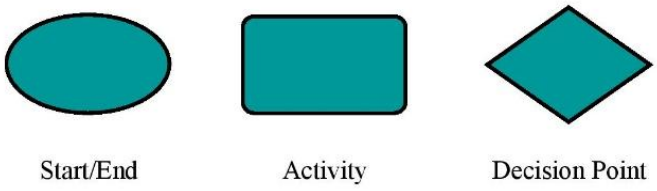

Figure 3 - Flowchart Symbols

Heher and Chen (2017) explains that the process mapping method begins by identifying the scope of the process to be analyzed, including its start and end points. Stakeholders, including those directly involved in the process, are consulted to gather detailed information about the steps involved. These steps are then arranged in a logical sequence, often using standardized symbols to represent different actions, decisions, and inputs/outputs. The goal is to depict not just the flow of work but also to uncover inefficiencies, bottlenecks, redundancies, and areas for improvement.

Heher and Chen (2017) concludes that process mapping offers several benefits, such as better communication among team members, improved process understanding, and enhanced decision-making. It helps teams pinpoint where problems occur, which leads to targeted solutions. Additionally, by documenting processes visually, organizations can create a shared reference that promotes consistency and facilitates training, making it an essential tool for continuous improvement and optimization.

3.7 Data Gathering, Data Analysis & PFMEA

The second set of interviews highlighted certain process steps which are demanding for the AE (A.2). By examining data connected to these process steps, the severity of the issues could be quantitively assessed.

To determine what data and what metrics would be interesting to assess, the CTQ concept was used. By making a CTQ tree, relevant metrics could be determined in a structured way. This was done by identifying the main requirement, drivers, CTQs and measurements.

The process of data gathering was conducted through collaboration with SE. After making inquiries and reaching out to various stakeholders for relevant information, the data was provided. This data primarily consisted of numbers related to technical requests, which had been identified as a demanding process step, especially in terms of lead time. The data included which type of technical request was handled, the date it was issued, the date it was required to be resolved, and the date it was resolved.

By examining the data collected, a selection of interesting areas was analyzed. One of these areas was the dates on which technical requests were created, requested to be completed, planned to start, and finally completed. This data was aggregated to identify discrepancies between the different dates, such as the number of days that differed between when a request was made and when it was actually completed.

Another area of interest in the data collected was the descriptions belonging to each technical request that had been admitted. The descriptions were thematized and coded to group the requests into categories, providing insight into how commonly different subjects cause a technical request. Results were presented in a pareto chart, displaying the occurrence of different themes. The data analysis was used to give a quantitative and objective perspective to the findings of the qualitative and subjective findings of the interview study.

To identify which parts of the process are the most demanding and potentially bottlenecks (*RQ2*), a PFMEA (Process Failure Modes and Effects Analysis) was conducted. Based on the process mapping, described in Chapter 3.6, process steps could be listed, which is the first step of a PFMEA. Thereafter potential failure modes, effects, causes and current controls were identified for each process step. Belonging to these are the rating system in Severity, Occurrence and Detection, resulting in a Risk Priority Number (RPN). For this analysis, detection was not used, as it was deemed to be too complex to estimate from an external perspective. This made the RPN values lower than usual, but it does not affect the results since only the relative differences between RPN values matter.

3.7.1 Theory - Data Gathering, Data Analysis & PFMEA

Data gathering and analysis are fundamental components of research that involve systematically gathering information and interpreting it to derive meaningful insights. Creswell and Creswell (2017) explains that effective data collection and analysis enable researchers to identify patterns, test hypotheses, and validate findings. The benefits of this process include the ability to make informed decisions, improve processes, and enhance the overall understanding of the research subject (Creswell & Creswall, 2017).

The importance of combining qualitative insights with quantitative data analysis is well-documented in the literature. For instance, Creswell and Creswell (2017) explains that integrating both types of data can provide a more comprehensive understanding of research problems. This combined approach allows for the validation of qualitative findings through quantitative measures, thereby enhancing the reliability and depth of the research outcomes.

CTQ Tree

The Critical to Quality (CTQ) Tree translates customer needs into specific, measurable performance requirements (Brook, 2022). It starts with categorizing needs into quality drivers, which are refined into actionable CTQs. This tool ensures all critical aspects are addressed, enhancing product quality and customer satisfaction (Brook, 2022).

Thematic Analysis

Thematic analysis involves identifying and analyzing patterns within coded data, as described by Wæraas (2022). Initially, segments of text are labeled with codes that capture key ideas. These codes are then grouped into broader themes, which are refined to ensure they accurately represent the data. This method is useful for qualitative research as it can help to uncover meaningful insights and understand underlying values embedded in the text (Wæraas, 2022).

Pareto Chart

The Pareto Chart is a powerful tool used to identify and prioritize the most significant factors in a dataset (Brook, 2022). It combines a bar chart and a line graph to display the frequency of different categories and their cumulative impact. Brook (2022) states that by focusing on the "vital few" causes that contribute to the majority of problems, the Pareto Chart helps organizations target their efforts effectively, improving quality and efficiency.

PFMEA

Process Failure Modes and Effects Analysis (PFMEA) is a systematic method for evaluating processes to identify where and how they might fail and evaluate the relative impact of different failures to prioritize the most critical issues (Sharma & Srivastava, 2018). The analysis involves listing process steps, identifying potential failure modes, their effects, causes, and current controls, and then rating these factors in terms of severity, occurrence, and detection. The resulting Risk Priority Number (RPN) helps in identifying the most critical areas that require attention. This structured approach ensures that the most significant risks are addressed first, thereby enhancing the reliability and efficiency of the process (Sharma & Srivastava, 2018).

3.8 Improvement Generation & Formulation

To outline which problems, as identified in the PFMEA, that should be addressed first an Impact-Effort Matrix was utilized. Complementing the PFMEA, the matrix served as an important tool for evaluating and prioritizing problems of the maintenance planning process based on the effort required to implement solutions to them, considering factors such as time, cost, and resources, and the impact they would have on the process, such as reducing lead time or enhancing quality. The problems were plotted on a two-dimensional matrix, with effort on horizontal axis and effect on the vertical axis. This visualization was created to highlight areas that could provide significant improvements with minimal effort, as well as those that might require more substantial investment but offer considerable benefits.

To address the problems found most important to improve, various meetings were held together with personnel at SE which involved brainstorming and generation on what potential solutions could be. These meetings aimed at addressing three different improvement areas, based on the Impact-Effort Matrix and the conclusions made in Chapter 6.4. The Impact-Effort matrix was the foundation for long-term goals, while time-consuming process steps served as the foundation for short-term fixes. Furthermore, involvement of personnel provided a perspective of what is feasible to implement at SE. The goal was to leverage the diverse perspectives and expertise from the personnel to identify innovative, yet functional solutions that effectively improve the problem areas. The information and ideas provided were reviewed and the authors made their own judgement on what to include. The most promising improvements were chosen, further developed and included in the final proposal to SE.

The formulation of improvements was divided into three areas, each with a single long-term goal and multiple short-term fixes. The short-term fixes are simpler improvements that are easier to implement, while the long-term goals are more challenging.

3.8.1 Theory – Improvement Generation & Formulation

The following section presents the theory supporting the generation and formulation of improvements.

Stakeholder Engagement

Engaging stakeholders in the improvement generation process is of great importance for ensuring practical, relevant, and supported solutions (Levin & Burke, 2024). According to Levin and Burke (2024), stakeholder engagement involves identifying and involving those with a vested interest in the project's outcome. This process gathers diverse perspectives, builds consensus, encourages ownership and commitment to the proposed improvements. Levin and Burke (2024) state that involvement of stakeholders leads to more effective and sustainable outcomes. Stakeholders' unique insights and expertise enhance solution quality, ensuring alignment with the needs and expectations of those implementing and benefiting from the improvements.

Impact-Effort Matrix

The Impact-Effort Matrix is a strategic tool used to evaluate and prioritize actions based on the effort required to implement them and the impact they will have on the process (Andersen, Fagerhaug, & Beltz, 2009). This matrix plots actions on a two-dimensional grid with effort on the horizontal axis and effect on the vertical axis, allowing for a clear visualization of which improvements can provide significant benefits with minimal effort, and which require more substantial investment but offer considerable returns (Andersen, Fagerhaug, & Beltz, 2009). By using the Impact-Effort Matrix, organizations can make informed decisions about where to allocate resources for maximum impact, ensuring that improvements are both effective and efficient, according to Andersen, Fagerhaug and Beltz (2009). In Figure 4 an example of how an Impact-Effort matrix can look is displayed as described by Andersen, Fagerhaug and Beltz (2009).

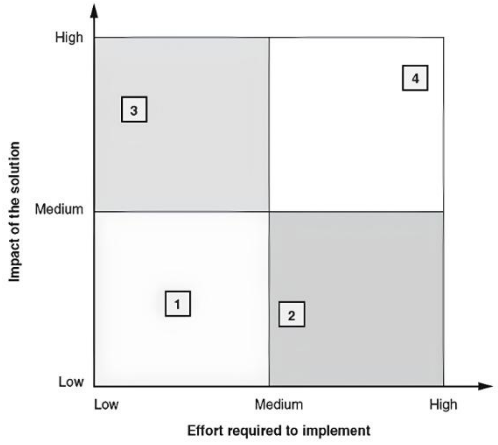

Figure 4 - Example of Impact-Effort Matrix (Andersen, Fagerhaug, & Beltz, 2009)

3.9 Ethics & Credibility

Ethics and credibility are foundational to academic research, ensuring that studies are conducted responsibly, and their findings are trustworthy (Säfsten & Gustavsson, 2019). This chapter explores these principles, emphasizing their importance in producing reliable research.

In conducting this study, careful attention was given to both ethical considerations and the credibility of the study. Ethical guidelines, as described in the Section 3.9.1, were strictly followed to protect participants and ensure the integrity of the research process. Credibility was maintained through thoughtfully designed methodological practices, as described in Section 3.9.1, ensuring that the findings are both valid and reliable,

3.9.1 Theory - Ethics & Credibility

The following section presents the theory supporting the previously mentioned considerations regarding ethics and credibility.

Ethics

Ethical considerations in research protect participants and ensure the study benefits society. The Swedish Research Council (2024) outlines four principles: reliability, honesty, respect, and responsibility.

Reliability ensures accurate and dependable research methods and findings (The Swedish Research Council, 2024). Honesty involves avoiding plagiarism and being transparent in documenting findings. Respect means valuing the impact on participants and stakeholders, while responsibility involves considering the practical consequences of the research. By following these principles, researchers can ensure their work is ethical and contributes positively to their field.

Credibility

Credibility in research involves validity, reliability, and objectivity, as described by Björklund and Paulsson (2012).

Validity measures whether the study accurately reflects what it aims to investigate (Björklund & Paulsson, 2012). Reliability ensures that the study's results are consistent when repeated under similar conditions. Objectivity minimizes personal biases, ensuring that the findings are based on factual data and transparent methodologies.

By adhering to these aspects, researchers can enhance the credibility of their work, making it a valuable contribution to their field (Björklund & Paulsson, 2012).

3.9.2 Quality of the Methodology

The quality of the methodology in this study is important for ensuring reliable and valid findings. The study followed an explorative approach, remaining flexible while exploring maintenance planning and late changes, allowing for the discovery of new insights and adjustments as needed. Various data collection methods, including document reviews, literature studies, interviews, and process mapping, provided a comprehensive understanding of the research problem and reduced bias.

The research process involved continuous refinement, especially in developing the process map and interview questions. Tools like PFMEA and the Impact-Effort Matrix helped analyze data and identify areas for improvement. Clear documentation of interviews, as presented in the Appendix A - Interviews, ensured transparency and allowed others to verify the findings. Key findings and results of the study, such as the process mapping and proposed improvements, were validated through feedback from experienced stakeholders, ensuring they accurately reflected real processes and challenges.

Ethical guidelines, as discussed in Section 3.9.1, were strictly followed, including informed consent and confidentiality, adding to the study's credibility. An evaluation of methods and findings was maintained throughout, ensuring accurate conclusions. This aligns with the principles of validity, reliability, and objectivity outlined in Section 3.9.1.

The combination of multiple data collection methods, continuous refinement, systematic analysis, and validation processes ensured that the findings are reliable, valid, and relevant. By maintaining these high standards, the study answers the research questions.

4. Theoretical Framework

The following chapter presents important theoretical concepts and frameworks that are deemed necessary to answer the purpose, and within the scope, of the study. This includes maintenance planning of gas turbines, data management, and project management under uncertain conditions.

4.1 Maintenance Planning Processes of Gas Turbines

Gülen (2019) explains that maintenance of gas turbines involves various activities aimed at maintaining the components in optimal condition and prolonging their overall lifespan. This encompasses regular inspections, part replacements, and repairs of any damaged components. According to Khalaf and Ali (2023) the primary objective of maintenance is to ensure smooth operation, reduce downtime, and enhance the efficiency and reliability of the gas turbine.

According to Raza and Hameed (2022) maintenance planning can be categorized into two main strategies: corrective maintenance and preventive maintenance. Each of these strategies includes several sub-strategies.

4.1.1 Preventive Maintenance

Preventive Maintenance is a proactive strategy aimed at minimizing equipment failures through scheduled maintenance activities. According to Raza and Hameed (2022), this approach involves planning maintenance based on the expected lifespan of equipment to avoid unexpected breakdowns. Furthermore, Raza and Hameed (2022) explains that preventive maintenance typically is carried out either at predetermined intervals or when specific conditions are met, reducing the likelihood of equipment failure. To further mitigate risks, maintenance is often conducted while the equipment remains operational.

Khalaf and Ali (2023) highlights that preventive maintenance plays a role in improving the performance and efficiency of complex systems, such as gas turbine units, by reducing unplanned downtime. As shown in Figure 5, preventive maintenance can be categorized into four main variations or sub-strategies (Raza & Hameed, 2022).

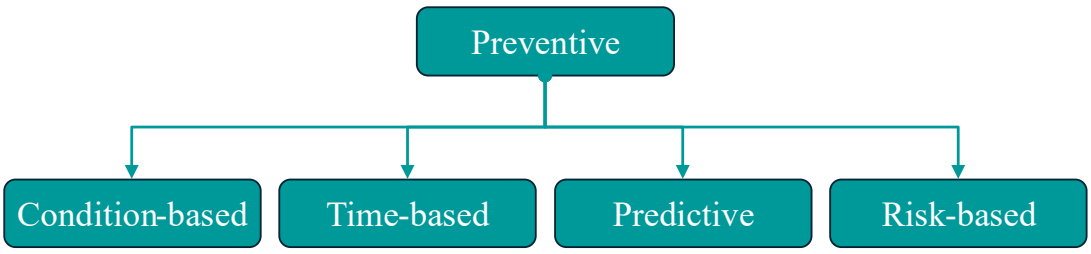

Figure 5 - The Variations of Preventive Maintenance Strategies

Time-Based Maintenance

Time-Based Maintenance (TBM) schedules maintenance tasks at fixed intervals, regardless of the equipment's current state. Kim, Ahn and Yeo (2016) emphasize that this method relies on time or usage metrics such as operating hours or calendar days. Raza and Hameed (2022) add that the goal is to conduct maintenance regularly to prevent unexpected failures and maintain consistent performance.

Risk-Based Maintenance

Risk-Based Maintenance (RBM) prioritizes maintenance activities based on the risk of potential failures. El- Thalji (2025) explain that this strategy involves evaluating the likelihood and impact of failures for different components. Raza and Hameed (2022) further describe that maintenance resources are allocated based on these assessments, with high-risk components receiving more frequent attention and lower-risk components being maintained less often.

Predictive Maintenance

Predictive Maintenance (PdM) uses data analysis and historical trends to forecast when equipment failures might occur. Hoffmann and Lasch (2025) explains that by monitoring various parameters and employing predictive algorithms, maintenance can be scheduled just in time to prevent failures. This approach aims to reduce downtime and extend equipment lifespan by addressing issues before they lead to breakdowns. Raza and Hameed (2022) also point out that PdM can lower maintenance costs and enhancing operational efficiency.

Condition-Based Maintenance

Condition-Based Maintenance (CBM) relies on real-time data from sensors to determine the best time for maintenance activities. Quatrini et al. (2020) states that this strategy involves continuous monitoring of equipment conditions and performing maintenance only when specific indicators suggest it is necessary. CBM helps prevent catastrophic failures by addressing potential issues early, based on the actual condition of the equipment. Raza and Hameed (2022) also notes that CBM can result in significant cost savings by avoiding unnecessary maintenance tasks.

4.1.2 Equivalent Operating Hours

Equivalent Operating Hours (EOH) is a metric used in gas turbine maintenance to estimate component wear and predict maintenance needs. Unlike simple time-based schedules, EOH provides a dynamic measure of operational time by accounting for varying operating conditions, according to Jingwen and Zhao (2012). The calculation of EOH involves several factors: Equivalent Operating Cycles (EOC), load, fuel quality, water injection, and exhaust temperature differences. Bohlin et al. (2009) presents the following formula for the calculation of EOH:

$$EOH = 5 \times EOC + \int C_x(t) \times C_f(t) \times C_w(t) \times C_{T7diff}(t)dt$$

Bohlin et al. (2009) explains that EOC represents the number of operational cycles, while $C_x(t)$, $C_f(t)$, $C_w(t)$, and $C_{T7diff}(t)$ adjust for load, fuel quality, water injection, and temperature differentials, respectively. These parameters ensure that EOH reflects real operating conditions more accurately than simple time-based measurements. Traditional EOH models often include broad safety margins to account for unmodeled factors like ambient air pressure, temperature, and rotational speeds. These conservative assumptions lead to shorter maintenance intervals than necessary, potentially increasing costs and reducing efficiency.

4.2 Data Management and Availability

In today's digital economy, IT systems plays an important role in how companies manage and utilize data. According to Urbach and Ahlemann (2019), IT has transitioned from a supporting function to a strategic resource, enabling businesses to enhance decision-making, improve efficiency, and gain a competitive edge. With the increasing reliance on data-driven insights, organizations must ensure data availability and implement digitalization strategies, such as efficient data indexing (Fagbola, 2018). As digital transformation accelerates, companies that effectively integrate IT systems into their data management processes will be better positioned for long-term success (Kim, Alavi, & Yoo, 2024).

4.2.1 Data Availability

Data availability is important for optimizing storage management and improving data center performance, according to Song et al. (2015). The shift from conventional on-site storage to cloud-based multitenant storage models enables centralized data collection, governance, and analytics. Song et al. (2015) states that a well-structured data availability framework allows for better resource allocation, reduced downtime, and improved decision-making for storage administrators. Additionally, centralized storage management facilitates seamless monitoring and governance, ensuring compliance and security (Song, Routray, Jain, & Tan, 2015).

Furthermore, Kim, Alavi and Yoo (2024) states that as technologies advance, the efficiency, and by implication, success of large corporations becomes increasingly dependent on the efficiency of information management. Effective decision-making, along with seamless data sharing, and improvements in resource allocation and data management are all key components of this (Kim, Alavi, & Yoo, 2024). Therefore, development of information management is essential for a company's continued success, especially at large corporations.

4.2.2 Digitalization - Data Indexing

Digitizing traditional methods of information storage can enhance accessibility and preserving valuable materials. Effective data organization and indexing are fundamental to this process (Fagbola, 2018). By adopting modern data organization practices, institutions can ensure that digital documents are easily retrievable and well-preserved for easy access (Fagbola, 2018).

Effective data organization involves establishing a logical file organization system, adhering to a consistent naming convention, and incorporating metadata and tags for efficient indexing (Meghanandha & Naik, 2025). Meghanandha and Naik (2025) highlight that metadata standards such as MARC and Dublin Core provide essential frameworks which promotes consistency and interoperability across diverse platforms. These standards help in creating a uniform structure for metadata, which is crucial for effective management and retrieval of digital information (Meghanandha & Naik, 2025). They also state that a consistent naming convention ensures that documents can be located swiftly, as they follow a uniform file format and structure which aids users in creating files that are easy to read and understand.

Furthermore, Fagbola (2018) emphasize that a well-defined naming convention reduces the time spent searching for documents and minimizes errors in document retrieval. Fagbola (2018) also argues that the increasing volume of information requires the automation of processes such as indexing and abstracting to manage vast amounts of data efficiently. Automated indexing techniques, such as natural language processing and machine learning, can significantly enhance the accuracy and speed of indexing large datasets according to Fagbola (2018).

4.3 Project Management under Uncertainty

Uncertainty in project management refers to the unpredictable elements that can impact a project's outcome. Uncertainty can be seen as a type of risk, as it involves unpredictable elements that can affect project success (Lyon & Popov, 2022). Although, unlike risks which can be identified and quantified, uncertainties are often unforeseen and lack historical data for analysis. According to Lyon and Popov (2022), managing uncertainty involves understanding its sources and developing strategies to mitigate its impact. This includes creating flexible plans that can adapt to changing circumstances and incorporating contingency buffers to handle unexpected events (Lyon & Popov, 2022).

Table 1 - Strategies for Reducing Uncertainty

Strategy	Description
Reduce decision size	Break it into smaller steps.
Understand options	Knowledge reduces uncertainty.
Defer decision	Postpone until better understood.
Focus on one decision	Avoid combining multiple risks.
Consider worst case	Define credible worst-case outcomes.
Clarify outcomes	Estimate consequences and risks.
Understand context	Know stakeholders and objectives.
Stay flexible	Adjust as you learn more.
Remain objective	Keep emotions out of decisions.

In Table 1, a simplified overview of strategies for reducing uncertainty in decision-making, as proposed by Lyon and Popov (2022), is presented. The main purpose in these steps is to improve the clarity, structure and adaptability in decision-making processes (Lyon & Popov, 2022). By applying these strategies, decision-makers can navigate uncertainty more effectively and make more confident, well-grounded choices.

Project replanning is a fundamental aspect of project management, particularly in dynamic environments where initial plans often require modifications due to unforeseen disruptions. A multi-objective approach to replanning enables decision-makers to balance competing goals, enhancing both adaptability and effectiveness. According to Pozanco, Borrajo and Veloso (2023) traditional methods often prioritize a single objective, such as minimizing costs or maximizing efficiency, but real-world applications typically involve multiple, interdependent objectives.

Multi-objective optimization provides a structured framework for addressing these complexities by considering trade-offs between various goals. For instance, in manufacturing, replanning efforts must account for production time, cost efficiency, and product quality. Pozanco, Borrajo and Veloso (2023) introduce the GREPLAN approach, which formulates new replanning goals by solving a multi-objective optimization problem. By ensuring that adjustments remain within an acceptable range of the original plan, this method enables a more flexible and realistic response to deviations (Pozanco, Borrajo, & Veloso, 2023).

One challenge in multi-objective replanning is the real-time allocation of resources in response to changing conditions. Dynamic pegging addresses this issue by dynamically reassigning Work-In-Progress (WIP) to new or existing orders, optimizing resource utilization while minimizing disruptions (Moghaddam & Saitou, 2022). This technique is especially useful in multi-level, mixed-model production systems, where unforeseen disruptions, such as sudden order revisions or deadline changes, demand frequent schedule adjustments. The predictive-reactive rescheduling method proposed by Moghaddam and Saitou (2022) incorporates dynamic pegging to improve system responsiveness, ensuring that resources are efficiently realigned without causing major disruptions.

A similar challenge arises in software development, where project plans must frequently adapt to evolving requirements and team dynamics. In agile development, release plan rescheduling must balance multiple objectives, such as minimizing delivery time, reducing costs, and maintaining plan stability. García-Nájera et al. (2021) evaluate three multi-objective optimization approaches for addressing this issue, highlighting the importance of managing trade-offs between conflicting priorities while ensuring the efficiency of optimization methods.

4.3.1 Logistics Practices

The logistics industry involves complicated supply chains in a dynamic and fast-changing environment, which means that there are a lot of uncertainties. Some examples of these uncertainties are fluctuating customer demand, unforeseen disruptions in supply and shifts in global politics (Christopher, 2016). To manage these challenges, companies work to improve processes like stock management, transportation planning and demand forecasting. According to Christopher (2016), these improvements help ensure that deliveries are made on time and costs remain low, even when unforeseen events occur. Christopher (2016) argues that the main challenge in logistics is to find the right balance between different objectives like minimizing transportation costs while reducing delivery times and maximizing service quality. He further explains that techniques such as multi-objective optimization and predictive analytics are employed to forecast future demand and proactively adjust operations.

Examples from the Industry

One example of a resilient operational strategy is seen in DHL's approach to logistics. DHL uses advanced data analysis and scenario planning to manage uncertainty in global supply chains (DHL, 2012). The company keeps a constant watch on its supply chain with real-time information so it can quickly detect and, if needed, respond to any issues. At the same time, DHL utilizes scenario planning to assess the effects of possible disruptions and prepare contingency measures. Furthermore, DHL emphasizes the importance of working closely with its supply chain, ensuring that all stakeholders are synchronized. This collaboration helps to solve problems quickly and mitigates the potential impact of unforeseen events (DHL, 2012).

In navigational planning, apps like Waze use routing optimization to suggest the fastest and most efficient travel paths, as notes by Sari et al. (2017). By collecting real-time information from its large user network and applying advanced algorithms, the app can adapt its suggestion based on current traffic, road closures, and other relevant factors. Sari et al. (2017) explains that this real-time routing not only minimizes travel delays but also enhances the overall driving experience, particularly in heavily congested urban areas.

Both delivery logistics and navigational planning depend on the strategic use of real-time data, predictive analytics and collaborative approaches to navigate uncertainty in planning. These techniques allow for maintained efficiency and service quality even when confronted with unforeseen disruptions.

4.4 Co-Creation of Value

According to Prahalad and Venkat (2004), co-creation is a business approach that emphasizes the joint creation of value by both the company and the customer, rather than the company simply trying to please the customer. In this model, customers are not passive recipients of products or services; instead, they are actively involved in shaping their own experiences to suit their individual contexts. This means that customers participate in defining problems and finding solutions alongside the company, resulting in a more collaborative relationship.

Co-creation also requires companies to innovate the environments in which these experiences take place, allowing for new forms of collaboration and engagement, as stated by Prahalad and Venkat (2004). By experiencing the business as customers do in real time, companies can better understand customer needs and adapt quickly. Ultimately, co-creation transforms the traditional business-consumer relationship into a partnership, where both parties work together to create value and meaningful, individualized experiences.

4.4.1 Interdepartmental Co-Creation

Kocsis, Gert-Jan De and Briggs (2015) states that co-creation meetings are a special type of organizational gathering where the concept of co-creation is used interdepartmentally to come together and collaboratively produce tangible results. Unlike typical meetings that may focus on updates or planning, co-creation meetings are designed to harness the collective creativity and expertise of participants to generate concrete deliverables.

Furthermore, Kocsis, Gert-Jan De and Briggs (2015) states that effective facilitation plays a role in guiding these sessions, helping groups navigate the collaborative process and achieve their goals. Central to successful co-creation meetings are patterns of collaboration, repeated ways in which people work together.

According to Rill (2016), resonant co-creation is an innovative framework designed to drive strategic innovation and organizational change by focusing on transforming the underlying worldviews of individuals and teams. Unlike general co-creation approaches, resonant co-creation emphasizes the importance of cultivating empathy and advanced communication skills through coaching and facilitation.

Rill (2016) claims that this process leads to a shift in how team members engage and interact, opening for new possibilities for creativity and innovation within organizations. The framework provides a clear model and practical techniques for facilitators, coaches, and leaders who want to encourage a more co-creative and innovative organizational culture.

5. Empirical Study of Maintenance Planning at Siemens Energy

This chapter presents the empirical findings of the study, focusing on maintenance planning at SE. This information is derived from the information and document gathering and the interviews with SE personnel, described in 3.3 and 3.5. The interviews are referenced using codes of the interviews which are found in Appendix A - Interviews. The set of codes representing the different interviews are (A.1.1), (A.1.2), (A.1.3), (A.1.4), (A.2) and (A.3). If a code is listed in the end of a sentence this is an internal reference to the interview.

Chapter 5.1 provides an overview of the current maintenance planning process for gas turbines within the company. Chapter 5.2 explores the causes of late changes in maintenance planning and in Section 5.2.1, the study examines how demanding different causes of late changes are, assessing their impact on the planning process. The effects of late changes are presented in Chapter 5.3, providing the answer for *RQ1: How is the maintenance planning process affected by late changes?* Lastly, Chapter 5.4 identifies and discusses the main problem areas currently affecting maintenance planning at SE.

5.1 Maintenance Planning

At SE, maintenance planning is a structured and complex process that integrates various strategies to ensure the optimal performance and longevity of gas turbines. This chapter will investigate how maintenance is planned, the processes involved, and the theoretical foundations that support these practices. The insights presented here are drawn from interviews with SE personnel and from theory presented in Chapter 4. In Figure 6 an approximate timeline for the project can be seen.

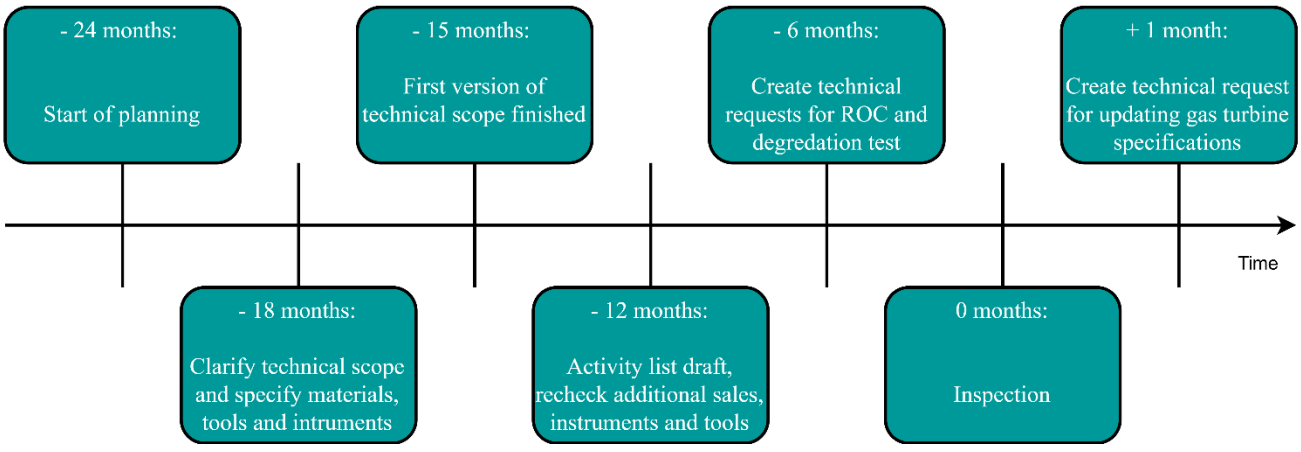

Figure 6 - Timeframe for inspection

The maintenance planning process at SE begins approximately 24 months before the scheduled inspection phase (A.3). The CCM and the client set preliminary dates for the inspection, which marks the start of the planning phase (A.3).

Thereafter follows a comprehensive assessment of the equipment's current state, historical data, and expected operational conditions. This assessment is important for setting the preliminary timeframe and scope for the maintenance to be done. 18 months before inspection, the scope is outlined, along with all the resources required for the inspection. Three months thereafter, the scope should be finished. 12 months before the inspection starts, the scope and timeframe are communicated with the customer and the main responsibility is handed over from CCM to the OPM (A.3). Thereafter, planning becomes more detailed and tools, instruments, personnel, materials are now ordered (if not done before). Six months after that, a technical request is made for a remote online check (ROC), to screen the gas turbine if something has been missing in the scope of the inspection. A month after the inspection, an additional technical request is made to document the inspection and update the specifications of the gas turbine.

The process involves several steps and stakeholders. The AE is one of the main stakeholders and plays an important role in developing and managing maintenance plans, ensuring compliance with technical guidelines, and coordinating technical issues with support from various departments (A.1.1). Furthermore, the AE is responsible for determining the scope of the inspection, which involves reviewing the contract and assessing the actual maintenance needs of the gas turbine (A.1.1). This assessment is partially based on the accumulated EOH of the components, which are compared against the engine life documents (A.2). The scope includes four main lists: tools, instruments, activities, and materials (A.1.4). These lists are derived from standardized templates but are customized to suit the specific requirements of each inspection. The AE ensures that the scope is comprehensive and accurate, minimizing the risk of unforeseen issues during the inspection.

Once the scope is defined, the planning process involves creating detailed activity lists, report templates, and technical documentation to guide the maintenance team. This documentation ensures that all necessary information is available to the site personnel, enabling them to perform the job efficiently and effectively (A.1.1; A.1.4).

If, for example, the AE is unable to access information needed for a particular scope, a technical request is made. There are several specific scenarios where the AE issues a technical request. A technical request involves submitting an inquiry to the Overhaul and Parts Department, which holds and assesses relevant technical information, sometimes classified. These requests can take more than three months to be resolved (A.1.4; A.2).

The planning process relies on many different types of data. The data flow for maintenance planning is complex, involving multiple systems and data sources, such as SAP, PLM, and the AED. SE utilizes various IT systems to collect, store, and analyze data related to gas turbine operations. For example, the AED system consolidates data from multiple sources, providing the AE with a comprehensive view of the turbine's condition (A.1.2). However, challenges remain, such as incomplete or outdated data and the need for better integration between different systems (A.1.3).

The maintenance planning strategies outlined in Section 4.1.1 offer a framework for understanding how SE approaches this complex task. Preventive maintenance can be categorized into four sub-strategies: Time-Based, Risk-Based, Predictive, and Condition-Based, all of which are implemented at SE to some extent. This theoretical backdrop is important for understanding how these strategies are practically applied at SE. For example, SE's data analysis and real-time monitoring practices to predict potential failures and schedule maintenance activities are examples of Predictive and Condition-Based Maintenance (A.2). The proactive approach of preventive maintenance helps minimize downtime and prolong the equipment's lifespan.

In addition, the concept of Equivalent Operating Hours (EOH), as described in Section 4.1.2, is incorporated into the planning process to provide a dynamic measure of operational time, accounting for different operating conditions. This ensures that maintenance schedules are more accurate and reflective of actual wear and tear on the equipment, optimizing maintenance intervals and reducing unnecessary costs (A.2; A.3).

5.2 Causes for Late Changes

Late changes in maintenance planning pose significant challenges in the management of gas turbines. These changes can disrupt schedules and reduce the efficiency of maintenance operations, increasing costs. Understanding the causes of these late changes is an important part for developing strategies to mitigate their impact. This chapter will state the causes which contribute to late changes in maintenance planning based on insights from interviews which can be found in Appendix A - Interviews.

The identification of causes for late changes in maintenance planning began with a series of introductory unstructured interviews (A.1), as described in Section 3.5.1. Among these, the interview documented in A.1.4 had extra focus on late changes and provided particularly useful insights. The interviewee highlighted several issues, including outdated or incomplete data, mistakes in the scope and logistical challenges.

The six recurring causes for changes in the scope of maintenance planning, as identified and validated through the interviews, are as follows:

- **Part issues**
  Problems with obsolete or outdated parts, or supplier issues, are quite common (A.2). If parts become obsolete, they should be flagged in the SAP material master, and a replacement should in most cases have been identified. However, delivery issues from suppliers, especially for long lead time components, can lead to scope changes if parts cannot be delivered on time (A.2).

- **Tools/instruments**
  Availability issues of necessary tools and instruments can arise, but these are typically less demanding to resolve. If tools are unavailable, PMs often negotiate with customers to use their tools or find replacements. This problem is less time-consuming compared to others (A.2). E.g. during planning (>1m) tools/instruments are found not to be available.

- **Scope is wrong from beginning**
  If the initial scope of inspection is incorrect or incomplete, it can lead to significant rework and delays (A.2). This issue can stem from poor handovers between AEs or missing information due to personnel changes. While it can be quickly fixed once identified, it can have a substantial impact if critical steps are not executed as planned (A.2). E.g. things have been missing and need to be ordered late.

- **Change in external demands**
  Changes in customer demands are the most common cause of scope changes, particularly in certain regions where sales may promise customers changes without consulting the main office (A.2). These changes are time-consuming to resolve as they often require re-planning of the inspection and managing customer expectations (A.2). E.g. additional work is required either from extra sales or from customer demands.

- **Change in internal demands**
  Changes due to internal checks or updates can vary in time consumption. Simple additions are easy to manage, but significant changes, especially those affecting nobel parts, can be very time-consuming as they require additional instruments and extended on-site time (A.2). E.g. additional work is required either from ROC or due to change in e.g. part life length.

- **Personnel**
  The availability of key personnel can impact the scope if the right people are not available. This issue is significant but manageable with proper planning (A.2). In urgent cases, personnel from other regions can be brought in, though this involves significant administrative work and costs (A.2). E.g. during planning (~3m) key personnel are found not to be available.

The semi-structured interviews conducted in the second set (A.2) provided further validation and depth to the understanding of these causes. Some additional insights, although not primary factors, included communication and coordination issues, legacy systems and data accessibility, and human error and inconsistency in documentation (A.2).

Several interviewees pointed out that poor communication and coordination between departments, such as sales, engineering, and project management, often lead to late changes (A.2; A.3). Miscommunication or incomplete data capturing can result in incorrect initial scopes or missed updates, leading to last-minute adjustments (A.2; A.3). The difficulty in accessing comprehensive mechanical records from legacy systems was a recurring theme (A.2). Useful information is often buried in PDFs or non-interactive PLM systems, making it challenging to retrieve and use necessary data for planning (A.2). This lack of integration between different data systems further complicates the planning process (A.2; A.3). Human error, such as missing items or miscommunication, and delays in securing manpower can contribute to unforeseen changes (A.2). Additionally, the lack of consistency in updating information according to guidelines can lead to significant problems when this data is needed for decision-making (A.2).

5.2.1 Extent of Causes for Late Changes

Late changes in maintenance planning can be attributed to a variety of recurring causes, as described in Chapter 5.2. Each recurring cause is unique in the sense that they differ in terms of complexity and how demanding they are to solve. Understanding the extent and impact of these causes is an important part for improving the efficiency and reliability of maintenance operations.

From the interviews conducted, it is evident that changes driven by external requirements or late-discovered personnel or part issues, such as obsolescence in parts and personnel shortages, are consistently brought up as highly demanding (A.1.4; A.2). These issues often require extensive re-planning, risk analysis, and coordination among various stakeholders, making them time-consuming and complex to resolve (A.2). For instance, when a critical part becomes obsolete, it requires finding a suitable replacement, which can involve lengthy investigations, sourcing processes and potential delays in the maintenance schedule (A.1.1; A.2).

In contrast, issues like tool and instrument availability, as well as part issues identified early, tend to be less demanding (A.2). These problems can often be resolved through negotiation with customers about using alternative tools or by sourcing replacements in a timely manner (A.2). The relative simplicity of these issues lies in their predictability and the availability of straightforward solutions (A.2).

Scope issues, on the other hand, are usually easier to fix. The most typical case involves adding the necessary actions to the activity list, which can be managed with minimal disruption to the overall maintenance plan (A.1.1; A.2).

5.3 Effects of Late Changes

Late changes in project management, particularly in the context of maintenance planning for gas turbines, can have significant consequences. This chapter explores the effects of late changes based on interviews found in Appendix A - Interviews and insights of theory from Chapter 4.3.

In cases where unforeseen changes occur, the planning process becomes more dynamic. The team must quickly assess the situation, determine the necessary adjustments, and communicate these changes to all relevant stakeholders. This often involves updating the activity lists, reallocating resources, and conducting additional risk analysis to ensure that the maintenance task can be completed without compromising the operation of the gas turbine (A.1.4; A.2). This can involve adding new tasks, modifying existing ones, or even removing certain activities. Such adjustments often lead to a domino effect, where changes in one area lead to further changes in others. For instance, if a new component needs to be installed, this might require additional tools, personnel, and time, thereby affecting the entire project schedule (A.1.1).

Rescheduling is another important aspect impacted by late changes. The need to reallocate resources and adjust timelines can lead to potential extended outages, which in turn can disrupt the overall project timeline (A.1.4; A.2; A.3). This causes the date for inspection to be postponed.

Rescheduling also entails that certain components must run longer than intended, as the inspection is postponed (A.1.4). The inspection date is set with the purpose of conducting maintenance on parts when service is due. This is determined based on the components service intervals, which are specified in EOH or EOC (see Section 4.1.2). As the components surpass their service intervals, the entailed risk must be evaluated. The AE is in this case responsible for making a technical request (described in Chapter 5.1) and providing the conditional data required for risk analysis (A.1.4).

Late changes often lead to going back and contacting various members of the project team to ensure that everyone is aware of the new requirements and timelines (A.2; A.3). This can be a time-consuming process, as it involves coordinating with multiple stakeholders, including AEs, PMs, and logistics personnel (A.2).

One of the most significant effects of late changes is the potential for extended outages (A.2). When changes are made late in the planning process, it can often become challenging to come up with the necessary information and resources in time. This can lead to delays in project completion and extended periods of downtime, which can be costly for the customer and the organization (A.2). Extended outages not only impact the project's timeline but also increase costs. The need to reallocate resources, expedite shipping of parts, and potentially hire additional personnel can all contribute to higher project costs (A.2; A.3). This is particularly problematic in the context of gas turbine maintenance, where the costs associated with downtime can be substantial (A.2).

5.4 Current Problem Areas

In this chapter, problem areas which have been brought up by the personnel at SE are presented. The focus lies on data availability and communication between departments.

5.4.1 Communication between Departments

Effective communication and collaboration among different departments and stakeholders are essential for successful maintenance planning. However, SE personnel have reported significant challenges in this area (A.1.1; A.3). Miscommunication and lack of alignment between different teams can lead to incomplete or incorrect data being used in the planning process (A.3). The theory on data management (Chapter 4.2) and project management under uncertainty (Chapter 4.3) both highlight the importance of clear communication and coordination.

There are many parties involved when handling a late change as large parts of the planning process must be revisited. Excluding the AE, this usually includes project management, field service planning, logistics planning and field service personnel (Bring & Lindström, 2023). There is always a lead time on forwarding information between departments and several decisions must be made along the way, making the process intricate and time-consuming (Bring & Lindström, 2023).

There are further communication issues when it comes to late sales. AEs have noted that sales personnel sometimes promise changes to customers without consulting the technical teams, leading to last-minute adjustments that can disrupt the maintenance schedule (A.1.1). These late sales have emerged as a concern in common among the interviewees. This issue involves the sale of additional modifications or upgrades to customers, typically within 12 months of the inspection date. AEs have expressed frustration regarding the current sales processes, feeling that the Sales Department may not fully grasp the technical aspects of the scope and how these additional sales impact their work (A.1.1).

The need to update the scope often leads to significant extra effort (A.2), and there can be complications with certain elements of the scope that further complicate scheduling and on-site time. The nature of the problem points to the need for better communication between the department of AEs and the Sales Department.

Additionally, the handover of machines and transfer of experience between AEs are often inconsistent, resulting in gaps in important information (A.1.3).

5.4.2 Data Availability & Management

One of the most significant challenges in maintenance planning at SE is related to data availability and management. The personnel have highlighted that the availability of data is an important issue (A.1.1; A.1.2; A.1.3). The data required for effective maintenance planning is often scattered across various systems and formats, making it difficult to retrieve and utilize efficiently. This fragmentation of data leads to delays and errors in planning, particularly when the AE is creating the scope.

AEs frequently encounter problems with missing or outdated data, which complicates the planning process (A.1.1). The data flow map created to understand the complexity of data dependencies in maintenance planning reveals that information is often stored in non-searchable formats, such as PDFs, which hinders quick access and decision-making (A.1.2). This issue is exacerbated by the lack of centralized and standardized data systems, which would otherwise ease data retrieval and integration (A.1.3).

Moreover, the presence of obsolete parts can require changes to the maintenance scope, creating extra administrative work and potential delays. Inadequate documentation and data management exacerbate the issue, as obsolete parts may not be properly flagged in systems like SAP, leading to confusion among team members. One AE noted that if parts become obsolete, they should be flagged in the SAP material master, and a replacement should already be identified, however this does not always happen in a correct and timely manner (A.2.1).

Furthermore, there are certain instances where the AE is unable to retrieve specific information required for creating and updating the scope of the inspection. This means that the AE must make a technical request, which can take more than three months in some cases (A.1.4). The reason behind this limitation in data availability is that certain data is classified and managed by the Overhaul and Parts department (A.2).

A PM (A.3) points out in one interview that there is further need for a software which provides a clear overview for each project. As responsibility is transferred between different stakeholders, other stakeholders may be completely unaware of the status of the project.

The first interview (A.1.1) highlighted the need for a system which eases the workflow for determining the details when replacing specific components during an inspection. For specifying what materials, tools and activities are required for replacing a specific part, the AE must navigate through several lists, making the workflow unnecessarily complex (A.1.1). Hence, there is a need for a system in which you first specify which component is to be replaced, and then the system automatically specifies what materials, tools and activities are needed for that component.

The theory on data management (Chapter 4.2) emphasizes the importance of data availability and digitalization for efficient decision-making. The current state of data management at SE falls short of these theoretical ideals, highlighting the need for improved data indexing and integration practices.

6. Analysis of Late Changes in Maintenance Planning

This chapter will present the analysis of this study, focusing on the impact and handling of late changes in maintenance planning at SE. The chapter will provide the answer to *RQ2: What parts of the maintenance planning process are most time-consuming to handle when there are late changes in maintenance planning?*

The analysis is built upon the empirical findings presented in Chapter 5 and aims to provide a deeper understanding of the processes and challenges involved. Tools and methods for processing the empirical information and acquired data in this chapter are explained in Chapters 3.6 and 3.7.

Chapter 6.1 examines the impact of late changes on the maintenance planning process. Chapter 6.2 outlines the workflow for managing late changes, illustrated through a detailed process map that outlines the steps involved in handling late changes in maintenance. It also connects the causes of late changes to different parts of the process map.

In Chapter 6.3, the causes of late changes are rated based on how demanding they are to solve, which is then translated to a rating on the steps of the process map in Chapter 6.4. Chapter 6.5 seeks to provide a quantitative and unbiased perspective through data gathering and analysis, including the methodologies CTQ, timeframe- and thematic analysis. Chapter 6.6 presents a PFMEA to provide a comprehensive understanding of what are the potential problems occurring in the handling of late changes in maintenance planning. Finally, Chapter 6.7 wraps up the analysis and presents central ideas of Chapter 6.

6.1 Impact of Late Changes

This chapter presents analytical evaluations of different areas affected by late changes in maintenance planning of gas turbines. The insights are derived from empirical findings as described in Chapter 5.3, which highlight the need for flexibility and adaptability in managing late changes.

Late changes often lead to operational inefficiencies, such as increased downtime and reduced productivity. The ability to manage these tasks effectively is crucial for minimizing the impact of late changes on the overall project timeline, as explained by Moghaddam and Saitou (2022). For instance, last-minute adjustments can disrupt the workflow, causing delays and bottlenecks.

As noted by Khalaf and Ali (2023), the primary objective of maintenance is to enhance the efficiency and reliability of operation of the gas turbine and reduce the downtime. However, late changes can significantly hinder these objectives by introducing uncertainty into the planning process. This can cause unexpected issues requiring quick solutions. Lyon and Popov (2022) note that managing uncertainty means identifying its sources and using strategies like flexible plans and contingency buffers to adapt to change.

Late changes often lead to going back and contacting various members of the project team to ensure that everyone is aware of the new requirements and timelines. This can be a time-consuming process, as it involves coordinating with multiple stakeholders, including AEs, PMs, and logistics personnel. In this process, effective communication is essential to ensure that all team members are on the same page and that the necessary adjustments are made promptly, which is also supported by Lyon and Popov (2022).

Another particularly challenging aspect of maintenance planning for gas turbines is when rescheduling is inevitable. This is often the least preferred option as it will cause significant delays. To lessen the impact on the operation of gas turbines, precise (re)scheduling is important to minimize downtime and ensure operational efficiency, as stated by Khalaf and Ali (2023). Again, Lyon and Popov (2022) emphasize the importance of flexibility and adaptability in such scenarios.

Effective resource management becomes challenging with late changes, as reallocating personnel, tools, and materials on short notice can be difficult. This often leads to suboptimal use of resources. Poor resource management can increase project costs and reduce the overall effectiveness of the maintenance process, impacting profitability and customer satisfaction. Gülen (2019) explains that maintenance of gas turbines involves various activities aimed at maintaining the components in optimal condition and prolonging their overall lifespan. Late changes can disrupt these carefully planned activities, which could potentially lead to severe problems.

6.2 Process of Handling Late Changes

In Figure 7 and Figure 8 the process map of handling a late change in maintenance planning is illustrated. The purpose of creating this map was to provide an overview of the decisions and activities that this process consists of, as described in Chapter 3.6. There is a lack of knowledge and awareness in this area at SE, and this process map fills the gap by offering a structured visualization of the workflow.

Process mapping offers several benefits as described by Heher and Chen (2017), and these benefits are evident in this case. By documenting the process visually, the map serves as a valuable communication tool. It promotes a shared understanding among team members and can be used for training purposes. This shared reference helps ensure consistency in how late changes are handled, reducing variability and improving reliability.

Heher and Chen (2017) also highlight that process mapping helps uncover inefficiencies and areas for improvement. In this case, the process map has offered a more comprehensive understanding of the process, which is essential for determining bottlenecks and potential improvements in the maintenance planning process.

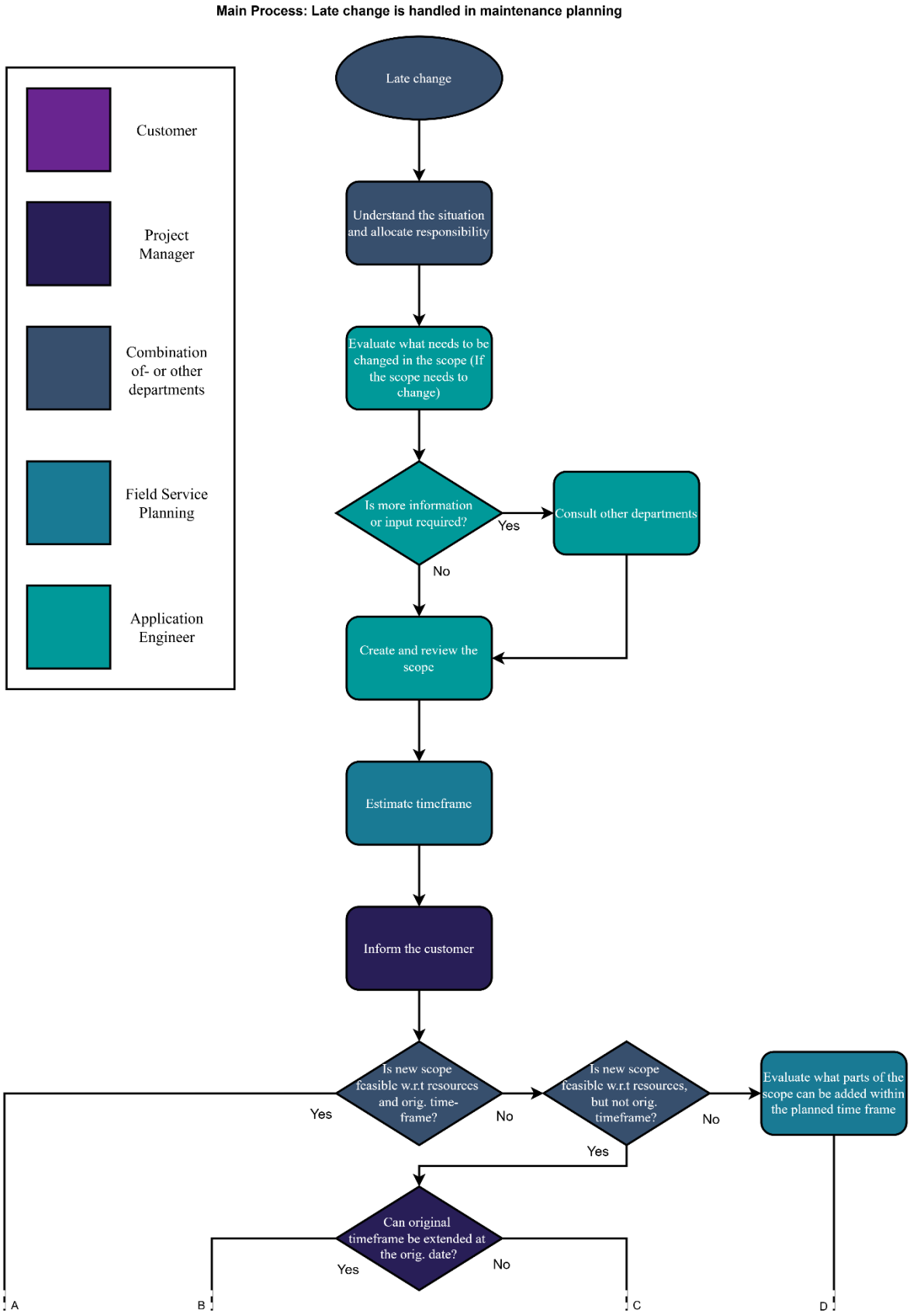

Figure 7 - Process Map: Handling of a Late Change (Part 1)

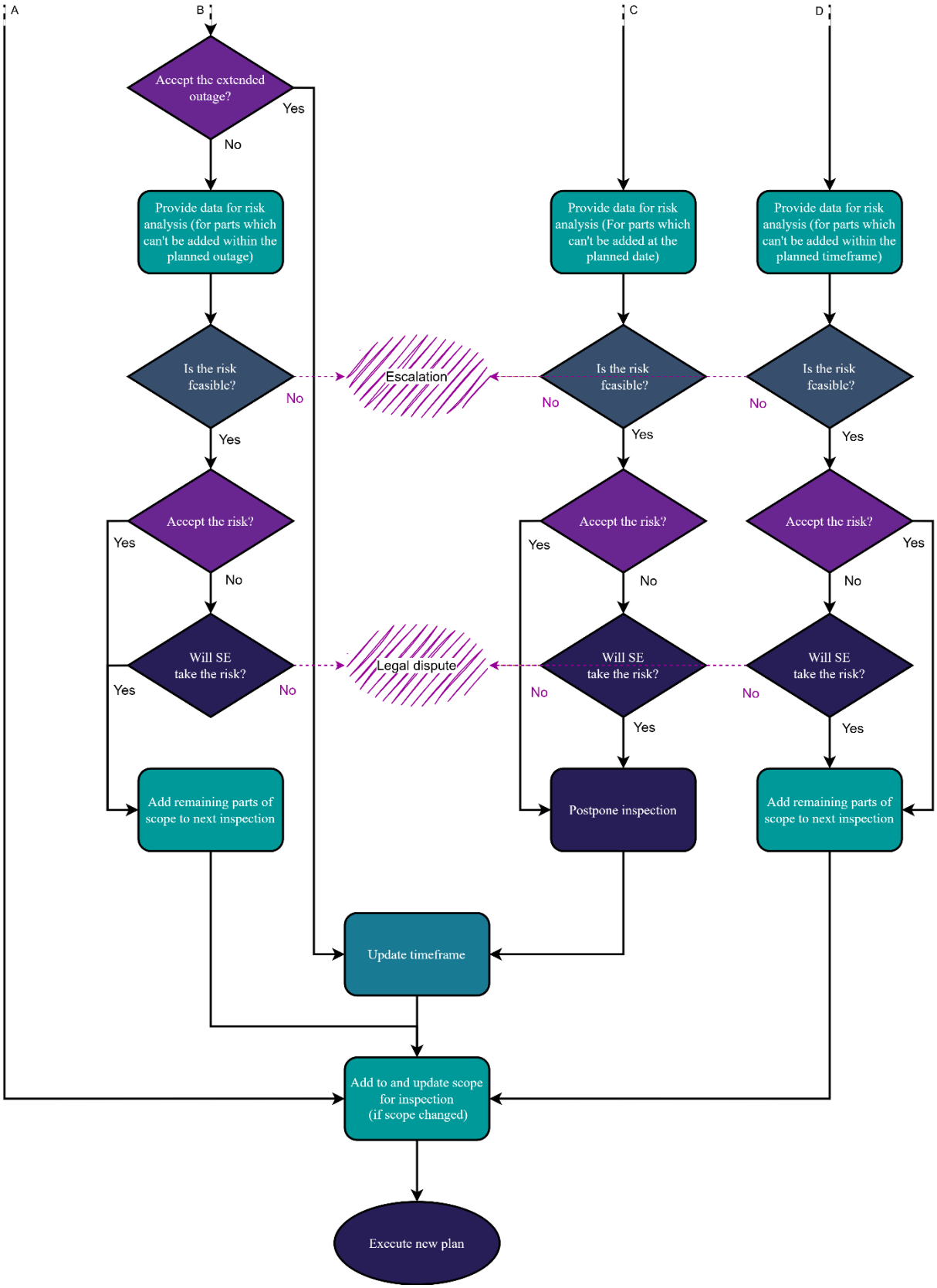

Figure 8 - Process Map: Handling of a Late Change (Part 2)

The process map describes the structured process for handling late changes in maintenance planning. It begins with understanding the situation and responsibility among key stakeholders, including the customer, PM, field service planning, and AEs. If necessary, other departments are consulted to gather additional input. The next step involves estimating an updated timeframe and informing the customer about potential changes.

The first decision is when evaluating if the new scope is feasible concerning available resources and the original timeframe. If feasible, there are no substantial issues, and the scope and timeframe will be updated accordingly.

If not feasible, the situation becomes more complex and involves multiple steps, where risk analysis and division are one of them. To begin with, there is a branching based on whether it is the scope or the timeframe that is infeasible. If the scope is infeasible, an assessment of which parts of the new scope can be added within the original timeframe. The remainder will be added to the next inspection on site.

If the timeframe is infeasible, an assessment if the timeframe can be extended is made. If this is the case the customer is asked if this works for them. If they accept, the scope can be added and the timeframe updated. If it is not accepted, only parts of the scope can be added within the original timeframe, and the remainder will be added to the next inspection on site. There also may be a situation where the timeframe cannot be extended due to SE and the inspection will be postponed to a later date.

In all cases where a risk analysis needs to be made, the feasibility and responsibility of risks is analyzed and divided. If risks are unacceptable there is a need for escalation to find a solution in complex scenarios. If they are acceptable, either SE or the customer needs to take responsibility for the risk. If the two parties cannot agree on a division of responsibility it may lead to a legal dispute. The final step involves adding to and updating the scope and potentially updating the timeframe.

6.2.1 Validation of Process Map

As described in Chapter 3.6, the process map was validated by collaboration with SE. The response to the validation request highlighted the need to indicate the distribution of responsibility for making decisions and performing activities. This meant addressing the perspectives of the PM, field service planning, the customer, other departments or combinations of departments in the process map (see Figure 7).

The information required for determining the different responsibility areas was retrieved from discussions with staff at SE and another process map (describing the maintenance planning process and its stakeholders) created by Bring & Lindström (2023). The reasoning behind addressing the distribution of responsibilities is that uncertainty regarding responsibility is an issue that causes delays and inefficiencies according to Lyon and Popov (2022). Furthermore, as responsibility shifts, there is lead time connected to communication between the parties (see Chapter 5.3).

The validation and verification of the process map ensures that it has real grounding in the organization and provides an accurate overview of how late changes are handled in the maintenance planning process.

6.2.2 Causes for Late Changes Connected to the Process Map

The following chapter presents and exemplifies different paths followed in the process map (Figure 7 and Figure 8) for each different cause for late changes in the maintenance planning, presented in Chapter 5.2. Figures in this chapter use the same color coding as in Figure 7 and the dashed lines indicate that the process continues outside the specific case(s) discussed.

- **Part issues**
  Problems with obsolete or outdated parts, or supplier issues, are quite common and can be divided into two exemplifying scenarios, as seen in Figure 9. If parts are obsolete (1), it means the AE must find a part which has similar attributes and can replace it. However, once a replacement is found, the problem is handled by adding the new parts to the scope and informing the customer. If there are supply chain issues and the part(s) cannot be delivered on time (2), the consequences can be severe, especially if the inspection must be postponed. Prior to postponing an inspection, a risk analysis is conducted, followed by a series of decisions regarding who is willing to accept the risk.

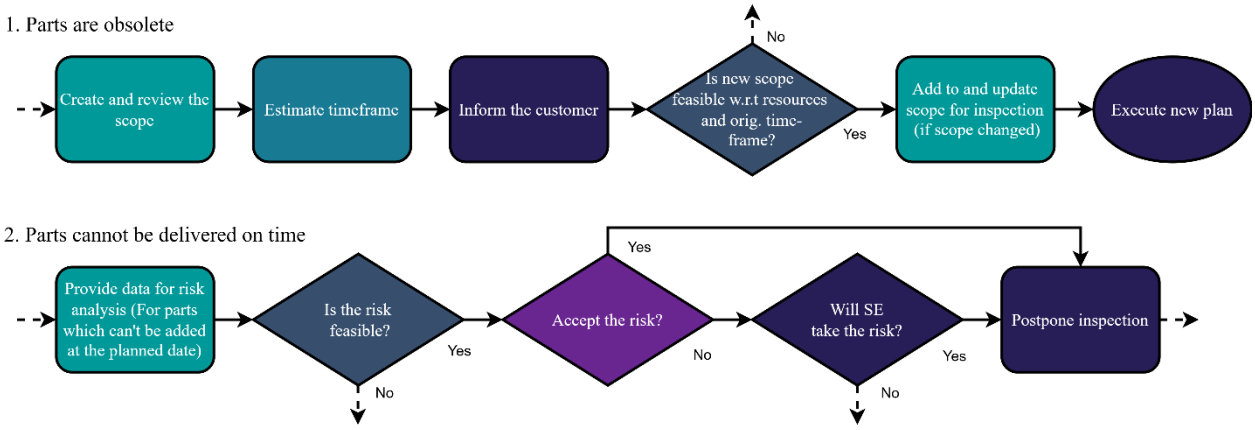

Figure 9 - Handling Part Issues

- **Tools/instruments**
  When tools or instruments are unavailable, the problem is usually solved by negotiating with the customer and using their tools, which could be a time-consuming process, but is usually solved without large repercussions. This process follows the path seen in Figure 10, where the focus lies on “Inform the customer”, but includes negotiations, not represented in the figure.

- **Scope is wrong from beginning**
  An incomplete or incorrect scope can cause severe repercussions, but usually the mistake is minor and easily handled. Handling a minor scope mistake follows the path seen in Figure 10. In most cases, the mistake does not affect the resource allocation or the timeframe. Hence, the cause is handled by adding what has been missing in the scope, the customer is informed, and the problem is solved.

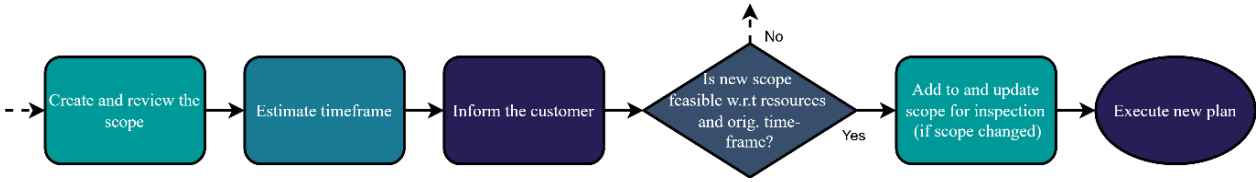

Figure 10 - Handling Issues the with Scope, Tools or Instruments

- **Change in external demands**
  A change in external demands, such as additional sales, is the cause which has the most extensive effect on the planning. This sometimes includes major scope changes, which could result in several different outcomes for how it is handled, depending on the extent of the scope change. In some cases, only minor changes must be addressed. As the extent of the changes are so varied, there is no usual path taken in the process map, the process may follow any of the possible outcomes.

- **Change in internal demands**
  Changes in internal demand usually leads to some type of scope change. Sometimes, there are minor scope changes which are easy to handle. Other times, it could lead to larger scope changes, as during ROC, it is discovered that noble parts need to be changed. Noble parts take a long time to install, usually causing the need for time extension for the inspection, as seen in Figure 11.

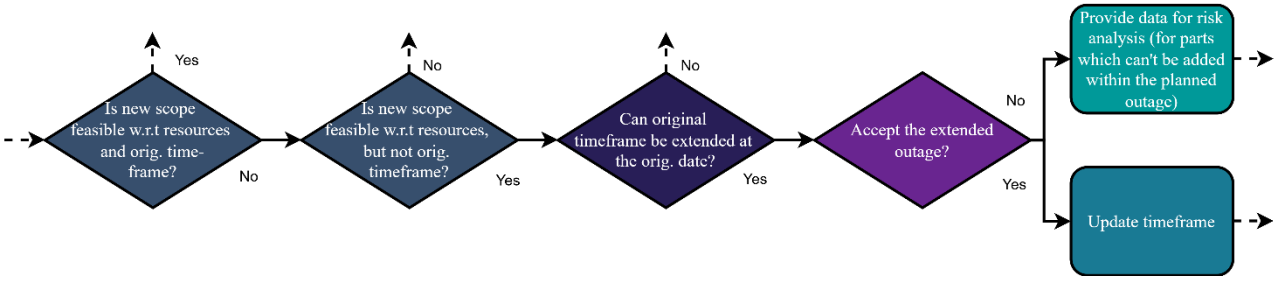

Figure 11 - Handling Changes in Internal Demand (Noble parts)

- **Personnel**
  Unavailable staff can lead to several scenarios, but it is usually solved by iterative communication between departments until a course of action is decided and the replacement of staff is found. The focus for handling these issues is the AE consulting other departments as seen in Figure 12, leading to an increased workload for On-Site Planning, for example.

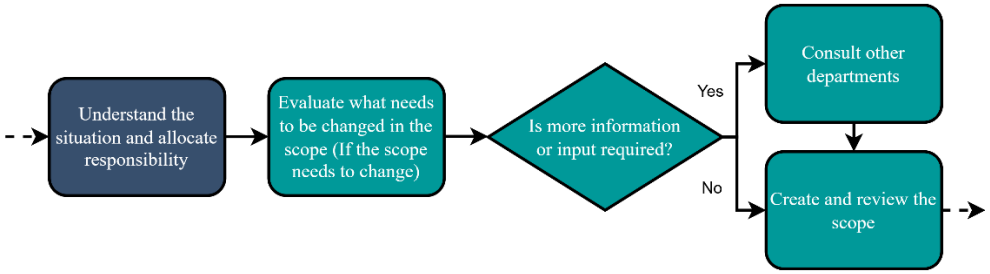

Figure 12 - Handling Issues Regarding Personnel

6.3 Rating of Causes for Late Changes

In Chapter 5.2, recurring causes to change the scope were identified. By analyzing the answers to the first question of the second set of interviews, as seen in Appendix A.2, the causes of late changes could be rated. The result of the relative rating of recurring causes to change the scope is displayed in Figure 13. As described in the methodology in Section 3.5.2, the relative rating number is based on the hierarchical relation between the six different causes for late changes and given a numerical value (1-6). The higher the relative rating number, the more demanding and time-consuming the cause is to solve.

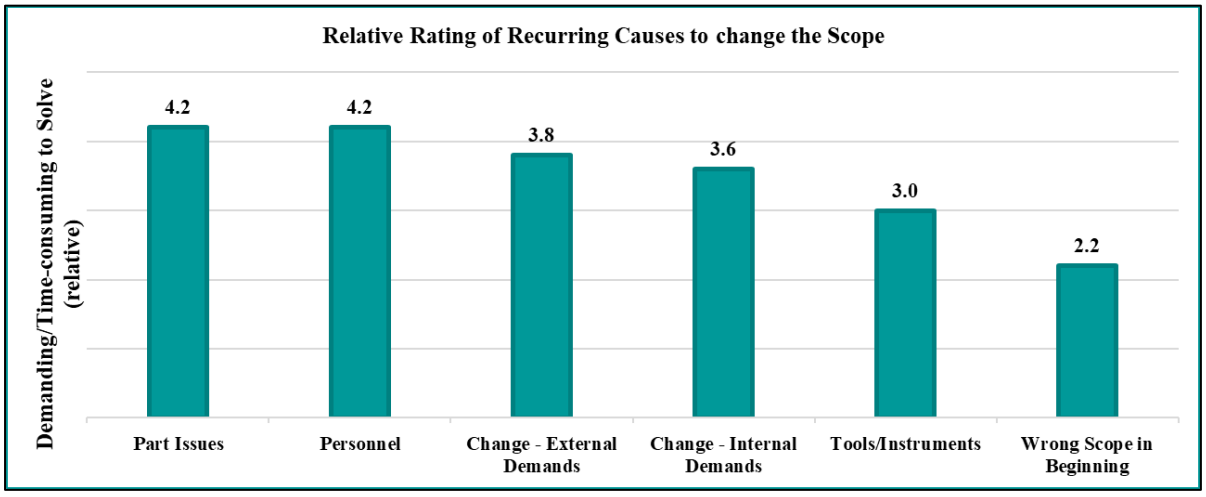

Figure 13 - Result of Rating Activity

The least demanding cause, though not unsubstantial, was identified as the "Wrong Scope in Beginning." This issue arises when the initial scope of the maintenance plan is inaccurately defined, leading to necessary adjustments as the project progresses. While this cause is relatively easier to address compared to others, it still requires attention to ensure that the scope is correctly established from the outset to minimize disruptions. A reason for the low rating could potentially be that the problem is more often a smaller mistake, and not necessarily an unknown that needs to be investigated. Therefore, a fix to the problem is often simpler, and less demanding to solve.

Following is "Tools/Instruments", rated as the second least demanding cause. This category encompasses issues related to the availability and functionality of the tools and instruments required for maintenance tasks. Although these problems rarely happen and, in most cases, can be prevented with planning and regular equipment checks, they still pose a challenge when they occur unexpectedly, necessitating quick responses to avoid delays.

"Change - Internal Demands" was identified as the third least demanding cause. These changes are driven by internal factors within the organization, such as shifts in project priorities or resource reallocation. While internal changes can be managed with effective communication and flexible planning, they still require a coordinated effort to ensure that the maintenance plan remains on track.

"Change - External Demands" rated as the third most demanding cause. These changes are influenced by external factors, such as new regulatory requirements, client requests, or market conditions. External demands are often more challenging to predict and control, making them more demanding to address. They require a proactive approach to anticipate potential changes and a responsive strategy to adapt the maintenance plan accordingly.

The most demanding causes for late changes were identified as "Personnel" issues and "Part Issues," both of which were rated equally demanding. "Personnel" issues include challenges related to staffing, such as shortages, skill mismatches, or unexpected absences. Personnel issues can significantly impact the maintenance schedule, as they directly affect the availability of skilled workers to perform necessary tasks. Addressing these issues often involves complex solutions, such as hiring additional staff, providing training, or reallocating existing resources.

"Part Issues" refers to the availability, quality, and delivery of parts required for maintenance activities. Part issues are particularly challenging because they can halt progress entirely if critical components are missing or defective. Resolving these issues often requires extensive coordination with suppliers, rigorous quality control measures, and contingency planning to ensure that alternative solutions are available when needed, thus it can be very demanding to find a solution.

By addressing the most demanding causes, i.e part issues, personnel and change in external demand, SE could potentially reduce the frequency and impact of late changes, leading to more reliable and effective maintenance planning.

6.4 Rating of Process Steps

Different causes decide what path is usually taken in the process map, as seen in Figure 7 and Figure 8. Comparing the different paths of causes to how they are rated, correlations pointing to demanding process steps are identified.

Part issues were rated as one of the most demanding scenarios to handle. As seen in Figure 9, part issues may cause postponing of the inspection, as resources are not available within the planned timeframe. Given the severity of a situation when the inspection must be postponed, it is reasonable that part issues are seen as highly time-consuming. Given how part issues were rated and its connection to risk of postponing the inspection, it can be concluded that the process steps leading to postponing the inspection are highly demanding. The most notable process step is the risk analysis, which according to a Senior AE, can take up to three months to complete.

Issues regarding the availability of personnel were rated as equally demanding as part issues. This is due to how demanding the process of handling the issue is when it comes to finding replacement personnel. As previously stated, this issue relies on communication between the AE and other departments, something that potentially takes a substantial amount of time.

Changes in external demand could result in many different cases, and it is therefore reasonable that it is rated in the middle of the causes in how demanding it is. Internal demands on the other hand are more predictable, either leading to small scope changes or large scope changes for noble parts, requiring on-site time extensions. As repercussions are relatively balanced between severe or minor, it is reasonable that changes in internal demands are rated in the middle. For issues regarding tools/instruments/mistakes in the scope, the issue is usually resolved quite quickly and without any impact on the timeframe.

Conclusively, by analyzing the causes, their time consumption rating and how the issues are usually resolved, it is evident that issues that have a potential impact on the timeframe are seen as time-consuming, as seen in Figure 14. The most notable process step is the risk analysis, which according to a Senior AE, can take up to three months to complete, and leads to extensive decision making. The need for time extension on-site causes the need for extensive communication with the customer and a series of decisions to be made which could in turn also lead to risk analysis. Furthermore, communication between departments and alignment within the team is seen as time-consuming, as there are several parties and decisions involved.

Figure 14 - Time-Consuming Process Steps

6.5 Data Gathering & Analysis

In this chapter, the problem areas identified in the interviews will be further analyzed, focusing on process and data management. Utilizing a CTQ tree, timeframe analysis, and thematic analysis, the chapter seeks to provide an unbiased perspective of the maintenance planning process.

6.5.1 CTQ Tree and Data Collection

In the process of gathering data to analyze, the first step was to understand what data could be useful for this study. This was done with the CTQ tree, providing a framework for translating needs into measurements. The resulting tree is displayed in Figure 15.

The construction of the CTQ tree began with identifying the primary requirement: efficient handling of late changes in maintenance planning. This requirement was then broken down into drivers: process agility, support infrastructure and change outcome quality. For each of the three drivers, specific CTQs were identified. The CTQs found were rescheduling frequency, streamlined approval process, resource availability, data availability, availability of support for urgent changes, adherence to changes specifications and change accuracy. Measurements were then established to assess these CTQs, including metrics like the percentage of time resources are available and the average time taken to complete a technical request.

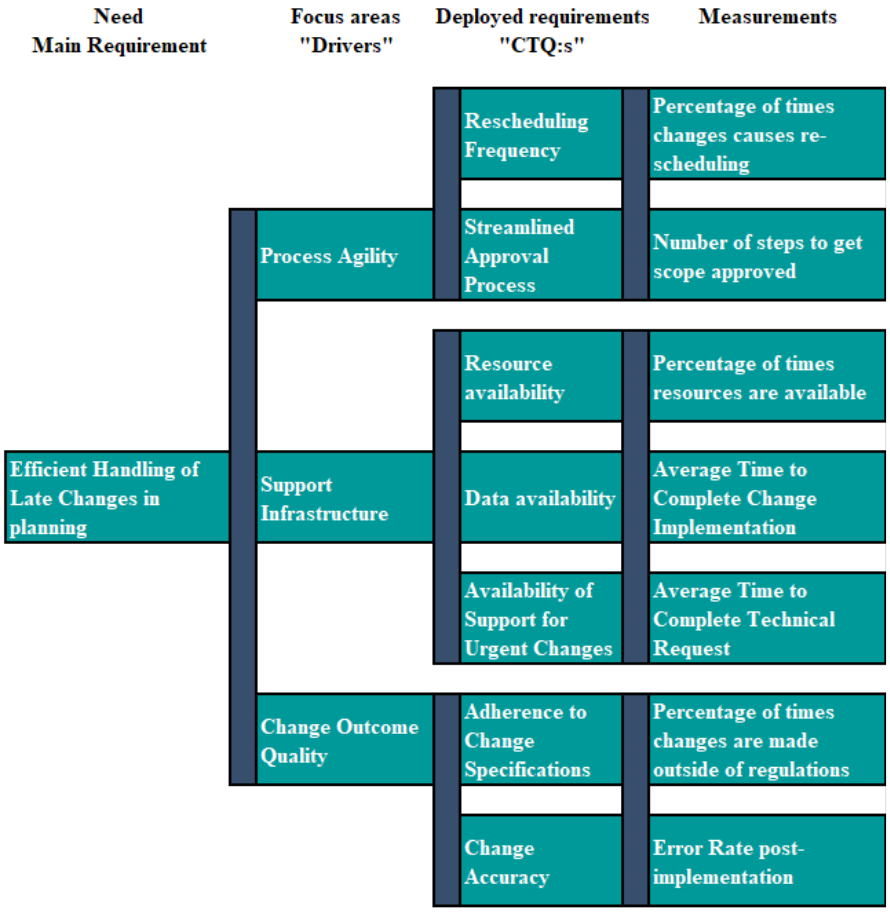

Figure 15 - CTQ tree, used for finding measurements for data analysis

Based on the findings of the CTQ tree, data collection was conducted through collaboration with various stakeholders at SE. It was a challenging task to get help in this matter, as many members of staff seemed to find it hard to comprehend what was being asked for or determine whether there was data regarding the measurements and statistics. After further explanation and contact with various colleagues, two data sheets were provided, containing information on technical requests from two different perspectives. The first perspective was all technical requests ordered by one AE during calendar year during 2024 and 2025. The second perspective was all technical requests handled by one department specifically working with risk analysis and the data was from the years 2020 to 2025. The data was further analyzed for understanding the content and lead times of technical requests.

6.5.2 Thematic Analysis of Technical Requests

To categorize and understand the common themes in technical requests, thematic analysis was conducted. This qualitative analysis provided insights into the themes of the request.

This analysis is based on a data set consisting of technical requests ordered by one AE, therefore not being a total investigation. The data contains a column with a description of the technical request which will be analyzed. This data is written by the person ordering the technical request and therefore some bias should be accounted for in the findings of this analysis.

Step 1: Data Reduction and Summarization

The analysis began with data reduction and summarization, where technical requests were coded into 16 different groups. The most frequent codes being EOH with 10 occurrences, gearbox issues with 8 occurrences, spare parts with 6 occurrences, and logic modifications and inspection both occur 5 times each. Further codes are not presented due to reasons of confidentiality.

Step 2: Categorizing Themes

The codes were then grouped into broader themes, being risk and inspection, gearbox and bearing issues, control systems and logic modifications, testing and monitoring, documentation and spare parts, and others.

Step 3: Code & Theme Structure and Description

In Table 2 the result of the thematic analysis is displayed. For each theme, the count of occurrences and description of each theme is presented.

Table 2 - Result of Thematic Analysis

Theme	Count	Description
Risk and Inspection	18	Assessing and managing equipment risks.
Gearbox and Bearing Issues	14	Maintenance and repair of gearboxes.
Control Systems and Logic Modificat	11	Upgrades and logic changes in systems.
Testing and Monitoring	6	Ensuring equipment functionality.
Documentation and Spare Parts	9	Managing documentation and spare parts.
Others	6	Requests that do not fit into the above categories

Step 4: Result

The result of grouping of the codes into themes can be interpreted in a pareto chart, as can be seen in Figure 16.

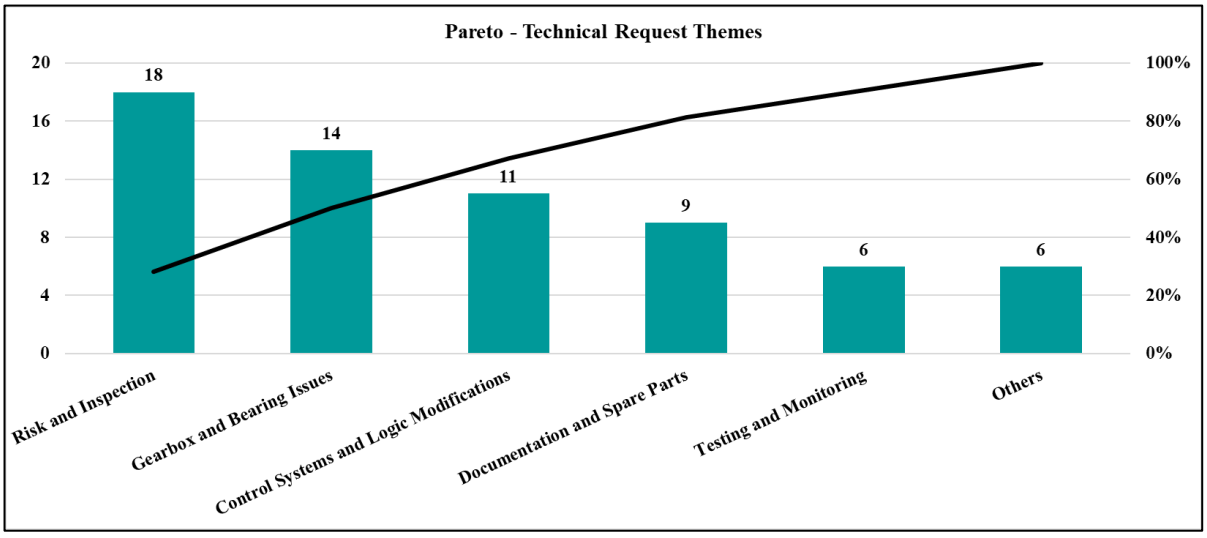

Figure 16 - Pareto Chart of Themes for Technical Requests

The Pareto chart illustrates that a large part of technical requests was related to risk and inspection, surpassing 20% of the cumulative percentage of the total. This indicates that this area is the most critical to technical requests and by focusing on improving the risk and inspection theme, problems related to technical requests are most effectively handled.

6.5.3 Timeframe Analysis for Technical Requests Related to Risk Analysis

To gain a deeper understanding of the delays and inefficiencies caused by late changes in maintenance planning, a detailed analysis of the timeframes associated with technical requests related to risk analysis was conducted. This analysis focused on identifying discrepancies between the planned and actual timelines for various technical requests. The result of this analysis is illustrated in a column chart in Figure 17. This analysis is based on a data set consisting of technical requests related to solely risk analyses.

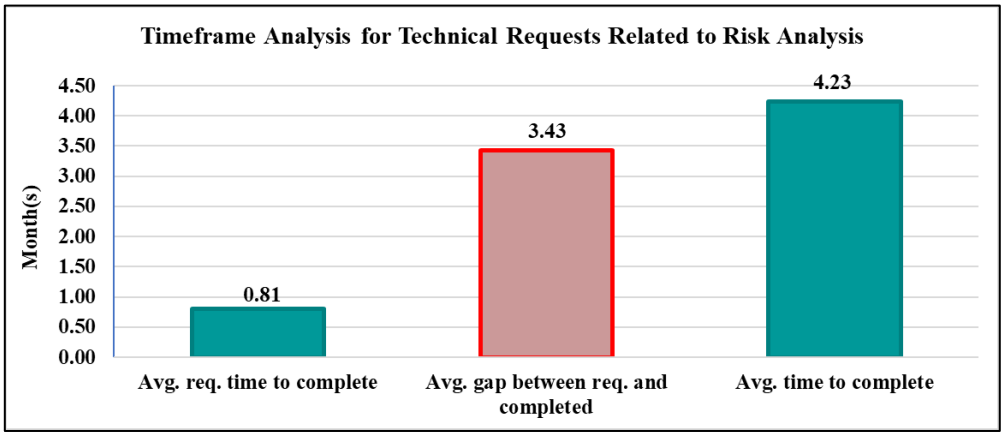

Figure 17 - Timeframes of Technical Requests (months)

The data revealed significant discrepancies between the average required time to complete tasks and the actual time taken. On average, the required time to complete tasks was 0.81 months, while the actual time taken was 4.23 months, resulting in an average gap of 3.43 months. This is a major gap and indicates that there might is an issue related to this discrepancy.

The required time to complete is usually set by the requester and is often seen as unrealistic due to internal lead times. This raises the question of why such timelines are used. Ideally, the required time should serve as a benchmark, meaning required and actual completion times should be more closely aligned. This would make the required time a more reliable expectation.

Unrealistic timelines can arise from poor communication between those requesting support and the technical teams, leading to misunderstandings about the work involved. External pressures, like customer demands, can cause requestors to set deadlines that are hard to meet with the current resources. Without historical data, requestors may rely on overly optimistic guesses instead of accurate information.

It should be noted however that the supervisor at SE, who has extensive experience of technical requests, claims that in many cases the technical request is solved a certain amount of time before it is reported as completed, as writing the report and documenting all specifications is a time-consuming process. This means that often, the AE requesting support has received it a certain amount of time before the technical request is marked as complete. The result of the analysis is, however, so substantial that this margin of error does not invalidate the gap between required and completed time.

6.6 PFMEA

As seen in Figure 18, a Process Failure Mode and Effects Analysis (PFMEA) was established to rank different failure modes within the process. The analysis assigns each failure mode a Risk Priority Number (RPN) based on its severity and occurrence, which provides a quantitative representation of what process steps to prioritize in terms of improvement. As the PFMEA is derived from the process map in Chapter 6.2, the responsibility is represented by the same colors in the same manner.

Process Name: Handling of Late Changes in Maintenance Planning				FMEA Date (Orig) 2025-03-20		
Solution / Process step	**Potential Failure Mode**	**Potential Failure Effects**	**SEV**	**Potential Causes**	**OCC**	**RPN**
Understand the situation and allocate responsibility	Miscommunication or understanding of responsibilities	Delays in decision-making, increased risk of errors	5	Lack of clarity in responsibility	5	25
		Duplication of efforts	3	Incomplete or unclear role definitions	4	12
Consult other departments and create the scope	Delayed input from consulted departments	Increased time-pressure	5	Slow response times	7	35
	Incomplete or inaccurate scope	Misalignment of planning, increased risk of errors	8	Inconsistent data formats, inexperience	4	32
Estimate timeframe	Incorrect timeframe estimation	Increased time-pressure, misprioritization of resources	5	Misjudgment, lack of information	4	20
Evaluating feasibility of new scope and timeframe	Incorrect feasibility assessment	Planning delays, resource misallocation	7	Incomplete data, lack of information	4	28
Evaluate what parts of new scope within orig. timeframe	Incorrect evaluation of parts that can be added	Misprioritization of parts to be done	6	Misjudgment, inexperience and/or lack of information	4	24
		Failure to complete due to either resource or time	7	Underestimation of timeframe or resources	5	35
Evaluate if timeframe can be extended at original date	Wrong estimation of time required	Misinformation to customer, fail to complete due to time	7	Underestimation of timeframe	4	28
		Misallocation of resources, customer dissatisfaction	5	Overestimation of timeframe	5	25
Risk analysis and risk division among stakeholders	Incomplete or inaccurate risk analysis	Unmanaged risks, potential planning failure	10	Lack of data, insufficient risk management practices	3	30
		Informing customer of incorrect risk	5	Lack of data, insufficient risk management practices	3	15
Escalation for urgent and complex scenarios	Delayed escalation	Prolonged project delays, customer dissatisfaction	6	Slow decision-making, unresolved issues	4	24

Figure 18 - Process Failure Mode Effect Analysis

The PFMEA for handling late changes in maintenance planning identifies potential failure points, their causes, and their impact on the process. Understanding the situation and allocating responsibility is the first step, but unclear roles and miscommunication can lead to delays and duplication of effort.

Inconsistent data formats, inexperience and slow response times when consulting other departments and creating the scope can cause increased time pressure and misalignment of planning. Similarly, errors in timeframe estimation due to missing data or incorrect assumptions lead to unrealistic scheduling and inefficient use of resources.

In the scope feasibility evaluation, failures in assessing the impact of changes can cause planning delays and misprioritization of tasks. If new elements are introduced into the scope without proper evaluation, misjudging their complexity can further disrupt the process.

When an extension of the timeframe is necessary, incorrect estimations can lead to misinformation, negatively impacting customer expectations and operational planning. Additionally, an incomplete risk analysis, due to insufficient data or a lack of structured risk management, can result in severe risks that could escalate into major planning failures or jeopardize the safety of on-site personnel.

If the process becomes too complex, delayed escalation to decision-makers can further slow progress and lead to unnecessary complications. By systematically addressing these risks, SE can improve decision-making, reduce inefficiencies, and ensure smoother maintenance planning despite late-stage changes.

As seen in Figure 18, the analysis highlights six potential areas which are to be further evaluated, based on their respective RPN values. These are deemed to need improvement and are therefore further analyzed in Chapter 7.

6.7 Analytical Conclusions

Late changes often lead to a less preferred and suboptimal solution to maintenance planning, partly due to the extensive rework required to address issues related to parts, personnel or any other cause for late changes to occur. This rework not only reduces the overall effectiveness of the maintenance process but also increases project costs, underscoring the need for improvements in the handling of late changes to maintenance planning.

The process for handling late changes in maintenance planning is outlined in the mapping of inherent activities and decision points involved. The mapping of the process offers a comprehensive understanding for the handling of late changes, but also an opportunity to evaluate it. The process is flawed, and there is room for improvement.

Comparing the quantitative and qualitative analysis leads to similar conclusions, pointing to time-consuming process steps. The qualitative analysis indicates that risk analysis, communication between departments and the series of decisions followed by a potential outage extension cause severe lead times. The PFMEA shows a similar result, indicating need for improvement for process steps regarding communication, availability of information and risk analysis. This is validated by data analysis, showing that the most common technical request, with a stake of more than 20%, is risk analysis. Furthermore, the data analysis shows that technical requests related to risk analysis take over 4 months to complete on average.

In summary, the analysis highlights that late changes in maintenance planning introduce inefficiencies, disrupt operational efficiency, increase project costs, and strain resource management. The combination of insights of the qualitative and quantitative analysis underscores a clear need for process improvements. This is primarily attributed to extended risk analysis procedures, poor communication and lack of information. To improve the maintenance planning process, it is most effective to tackle problems related to these problematic areas first, which will be done in Chapter 7.

7. Improvements in Handling Late Changes in Maintenance Planning

This chapter will present suggestions on improvements in the handling of late changes in maintenance planning at SE. The chapter will provide the answer to *RQ3: How could the handling of late changes in maintenance planning be improved, with regard to data and process management?*

The generation of improvements is based on two different sources of problem areas. The first source being the most time-consuming process steps as identified in Chapter 6.4. These are: "consult other departments", "can timeframe be extended at the original date?", and "provide data for risk analysis". These mainly provide the foundation for finding short-term solutions.

The second source for generation of improvements is the Impact-Effort matrix, derived from the PMFEA from Chapter 6.6. This mainly provides the foundation for finding long-term solutions. In Figure 19 below, the Impact-Effort matrix is displayed, where the most problems identified in the PFMEA can be seen. Among the six identified problems, four fall into the "easy wins" category, indicating they offer the highest impact relative to the effort required for implementation. Specifically, problems number 2, 3, 4 and 6 are most suitable for improvements due to their impact-to-effort ratio and will be prioritized in the generation of solutions. Problems 1 and 5, on the other hand, do not offer the same level of benefit for the effort involved and will not be included in the immediate improvement plans.

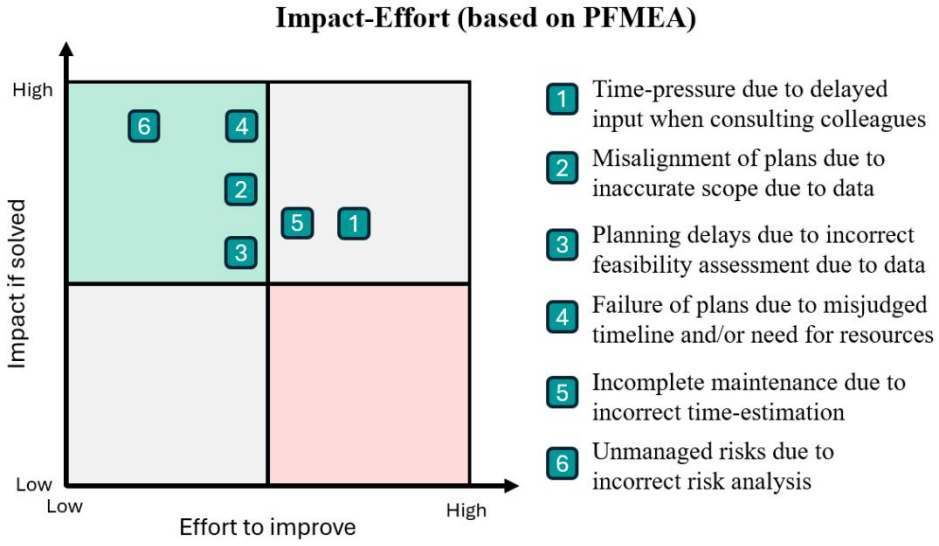

Figure 19 - Impact-Effort Matrix (based on PFMEA)

Chapters 7.1 to 7.3 aims to provide concrete short-term and long-term improvement suggestions regarding three specific areas: collaboration and communication between departments, data management and availability, and risk analysis/technical requests. The improvements provided are derived from suggestions from SE personnel, as is summarized in Appendix A.4, and further developed by the authors of this thesis. As explained in Section 2.2.1, the implementation of the improvements will not be considered. However, the improvement suggestions are aimed to be feasible in terms of time and economic investment.

7.1 Collaboration and Communication Between Departments

This chapter provides long- and short-term suggestions for improving communication and collaboration between departments at SE. These mainly concern collaboration within the project team of an inspection but could potentially be applied to increase responsiveness for other departments involved in handling late changes in maintenance planning.

7.1.1 Long-Term Goal

Co-creation of Value between the (O)PM and AE

AEs and PMs each bring unique expertise to projects, but their effectiveness is often limited due to their different priorities and perspectives. As described by Prahalad and Venkat (2004), co-creation is often aimed at customers, but it can also be used within teams, where members treat each other as internal customers. This approach encourages collaboration and ensures that everyone's needs and perspectives are considered in creating solutions together. Co-creation offers a structured approach for different roles to collaborate, enabling both to perform their individual tasks more effectively by leveraging each other's strengths.

According to Kocsis, Gert-Jan De and Briggs (2015) co-creation meetings are purposefully designed sessions and in this case, AEs and PMs would focus on producing concrete deliverables, such as project plans or technical solutions, rather than exchanging updates. Kocsis, Gert-Jan De and Briggs (2015) states that research shows that collaboration is most effective when it follows clear and repeatable patterns like brainstorming, prioritizing, and decision-making. By intentionally building these patterns into meetings, the teams can better integrate both technical and project management perspectives.

Rill (2016) states that recent research on resonant co-creation further emphasizes the transformative potential of this approach. Through facilitation and coaching, co-creation meetings help AEs and PMs develop empathy, awareness, and stronger communication. This deeper understanding of each other's challenges enables both roles to anticipate issues, align priorities, and make better decisions. Resonant co-creation also encourages creative problem-solving, leading to innovative solutions that neither group could achieve alone. Making co-creation a regular practice empowers AEs and PMs to perform their tasks more effectively while maintaining a more adaptive and innovative project culture.

7.1.2 Short-Term Fixes

Collaborate in Discussions on Feasibility of Late Changes

In the context of project collaborations, particularly between the AE and the OPM, establishing clear communication guidelines is important for effectively discussing the feasibility of late changes. As SE has expanded significantly over the years, the evolution of the working methods and data management practices has not kept pace with the growth. This has led to unclear responsibilities and challenges in coordinating among a diverse range of staff, making it increasingly difficult to schedule meetings and align on project objectives.

To enhance collaboration, it is important that any potential late changes are communicated promptly to all relevant team members. This helps avoid misjudgments in decision-making regarding late change approvals. When team members are informed of changes early on, they can assess the implications and provide input, ensuring that all decisions are made with a comprehensive understanding of the project's context.

Implementing clear guidelines for how to address late changes as a team would improve collaboration and communication. A concrete example of such a guideline could be that thorough time estimation is conducted early in the process of handling a late change. This would be communicated with all stakeholders to ensure that everyone involved are aware of potential lead times. This way, the stakeholders can plan around the lead times and adapt accordingly, similarly to the multi-objective GREPLAN approach described by Pozanco, Borrajo and Veloso (2023).

By establishing clear guidelines for addressing late changes, the alignment within the project team can be improved. This will not only improve the efficiency of the decision-making process but also enhance overall project efficiency.

Clarification and Standardization of Responsibility and Task Division

When late changes occur, clarity in responsibility is highly important to minimize uncertainty and ensure smooth workflow. During the kick-off meeting, held 24 months prior to the inspection, all areas of responsibility should be clearly defined. This would reduce uncertainty, which increases productivity, as described by Lyon and Popov (2022). The effective implementation of a decision tree (process map) can provide clarity regarding the responsibilities and roles. This should include all potential activities and decision points up until the inspection, including strategies for addressing various late changes. By proactively outlining these responsibilities, the planning phase can be improved, improving adaptability to unforeseen circumstances and leading to a more organized and efficient process.

In the face of late changes regarding inspection scopes, implementing standardized solution processes can significantly enhance efficiency and clarity, as stated by Heher & Chen (2017). For instance, while the specific parts and personnel required vary from case to case, the underlying process for addressing late changes often remains quite similar. Developing different standardized processes for different recurring scenarios can provide clarification for the specific task at hand, ensuring that all team members understand their roles and responsibilities.

While it is impossible to create standardized processes for every conceivable scenario, focusing on the most common and similar cases can provide significant benefits. By clearly defining roles, tasks and workloads using process mapping, overall project efficiency can be improved, and the risk of miscommunication is reduced.

Inspection Alignment Meetings

To improve team alignment, SE could implement inspection alignment meetings. These could, for example, be held on a biweekly basis from six months prior to an inspection as illustrated in Figure 20. These meetings would serve as a platform for the project team to discuss ongoing issues and align on problem-solving strategies, thereby minimizing potential misunderstandings. Additionally, it would be beneficial to consider possible late-change scenarios during these discussions, allowing the team to proactively prepare for any unexpected events. This repetitive and proactive approach can enhance readiness and ensure a smoother inspection process, as proposed by Kocsis, Gert-Jan De, & Briggs (2015).

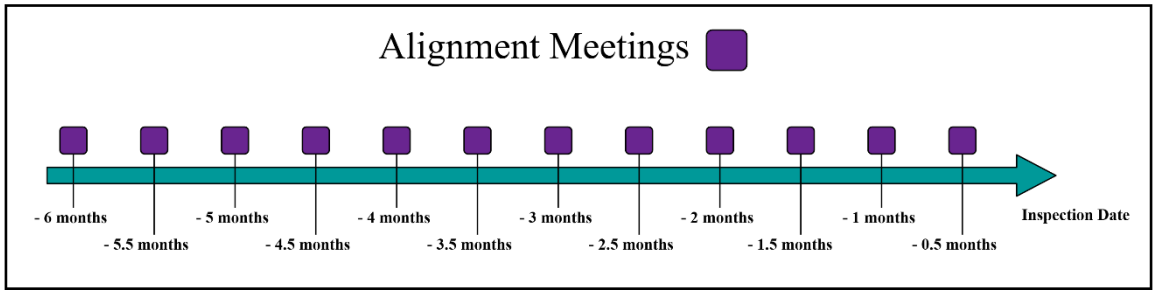

Figure 20 - Illustration of Alignment Meetings

7.2 Enhancing Management and Availability of Data

This chapter provides both long-term and short-term suggestions for improving the management and availability of data at SE. These improvements aim to address challenges related to outdated or incomplete data, logistical constraints, and inefficiencies in accessing information. As highlighted by Kim, Alavi and Yoo (2024), effective data management is essential for long-term success, which is directly relevant to the maintenance planning process investigated at SE. The suggestions are designed to improve overall project efficiency and provide the foundation for better decision-making when handling late changes in maintenance planning.

7.2.1 Long-Term Goal

Integration of Data in a Unified Project Management Platform

The integration of all machine-specific information and workflows into a single, unified project management platform could improve operations and project team collaboration. By pulling key data from existing software into one interface or dashboard, the platform provides a quick and comprehensive overview of project status. Tools like action-trackers can help visualize progress, identify bottlenecks, and ensure tasks are completed on time. This platform would be quite similar to the AED but instead tailored for project management. In essence, this platform would enhance collaborative assessments, reduce miscommunication and improve the overall efficiency of the project by allowing multiple members of the project team, AEs and PMs, to work together more effectively.

As noted by Urbach and Ahlemann (2019), IT systems have evolved from being mere support functions to becoming strategic resources that enable businesses to enhance decision-making and operational efficiency. A unified project management platform aligns with this perspective by centralizing task management, integrating communication tools, and enabling real-time project tracking. This approach not only simplifies collaboration but also improves project visibility, which is important for managing complex workflows and late-stage changes in maintenance planning.

SE has already made progress in this area with the development of the software platform "One PM." This initiative shows promise in unifying project management processes. However, as noted by a Senior AE, "One PM" currently lacks some functionalities, which limits its ability to fully meet the needs of the team. For example, issues related to access are currently a roadblock hindering project teams from making the complete transition to "One PM". While "One PM" is a good starting point, addressing these gaps would be essential to fully realize the benefits of a unified project management platform.

Digitization Initiatives

"Digitization Initiatives" encompass a series of transformative projects aimed at modernizing the accessibility, usability, and efficiency of historical and operational data through improvements to digital tools and processes at SE.

A first, key focus, would be to leverage artificial intelligence (AI) to digitize old records, converting outdated formats into a unified, searchable database that makes historical data, such as maintenance records for older machines, easier to access. As time has progressed, the formats used for mechanical records have evolved. From handwritten logs to digitized documents, the inconsistency in these formats can create barriers to finding specific information. For instance, an AE searching for maintenance records on an older machine may encounter a mix of documents written in different formats. This inconsistency not only hinders efficiency but also risks the loss of knowledge that could benefit current and future maintenance plans of gas turbines.

According to Fagbola (2018), digitizing traditional methods of information storage can enhance accessibility and preserving valuable materials. AI technologies can be useful in the digitization process by automating data extraction, recognizing patterns, and improving search capabilities over time. Automated indexing techniques, such as natural language processing and machine learning, can significantly enhance the accuracy and speed of indexing large datasets (Fagbola, 2018). This would significantly improve the workflow when working with older machines as the information needed would be more accessible.

Another important initiative within the same context is the implementation of data standardization practices to reduce errors and improve clarity. As highlighted by Meghanandha and Naik (2025), metadata standards such as MARC and Dublin Core provide essential frameworks for ensuring consistency, interoperability, and effective management of digital information across diverse platforms. By establishing consistent formats for data entry, such as part numbers, SE can improve the usability of information across different systems, making it easier to retrieve and analyze data. Standardization will not only improve operational workflows but also ensure the accuracy and reliability of information critical to field service tasks.

Lastly, an important digitization initiative would be to modernize Product Lifecycle Management (PLM) reports, which currently exist in static PDF formats that slow down issue resolution. By transitioning to more interactive formats or integrating PLM data directly into a unified project management platform, availability and usability of information could be improved.

Collectively, these digitization initiatives represent a cohesive effort to create a future-ready system that empowers teams to work smarter, faster, and with greater precision.

7.2.2 Short-Term Fixes

Improved Availability of Domain Data

Currently, there is a gap between domain data and application data, with some information not easily available for the main users, being the AEs. This limitation often forces AEs to submit technical requests or conduct risk analyses to obtain the necessary data. As Song et al. (2015) emphasize, a well-structured data availability framework can optimize resource allocation, reduce downtime, and improve decision-making. By collecting and presenting domain data in a more user-friendly and accessible format, SE can reduce the reliance on technical requests and empower AEs to work more independently. For example, integrating domain data into the AED or a similar platform would allow AEs to access the information they need without having to go through multiple time-consuming steps to find a solution to the issue.

Cross-Application Oversight

To improve the overall integration and functionality across various software systems, SE could designate an individual to have an overarching responsibility for monitoring the relationships between programs. This person would oversee updates, ensure interconnectivity, and facilitate communication between teams to maintain the integrity of the systems. By proactively managing these connections, SE can prevent disruptions and improve the overall efficiency of maintenance planning.

Improved User Interface (Down-Up Lists)

As of now, when a specific component is to be replaced, the AE must go through several lists of activities within the application to sort out what is needed for that specific component. An alternative system could be implemented, where users first select the component that they are working on, and the system automatically assigns the relevant activity lists. This "down-up" approach, as seen in Figure 21, would improve the workflow by reducing the number of steps required to retrieve necessary information.

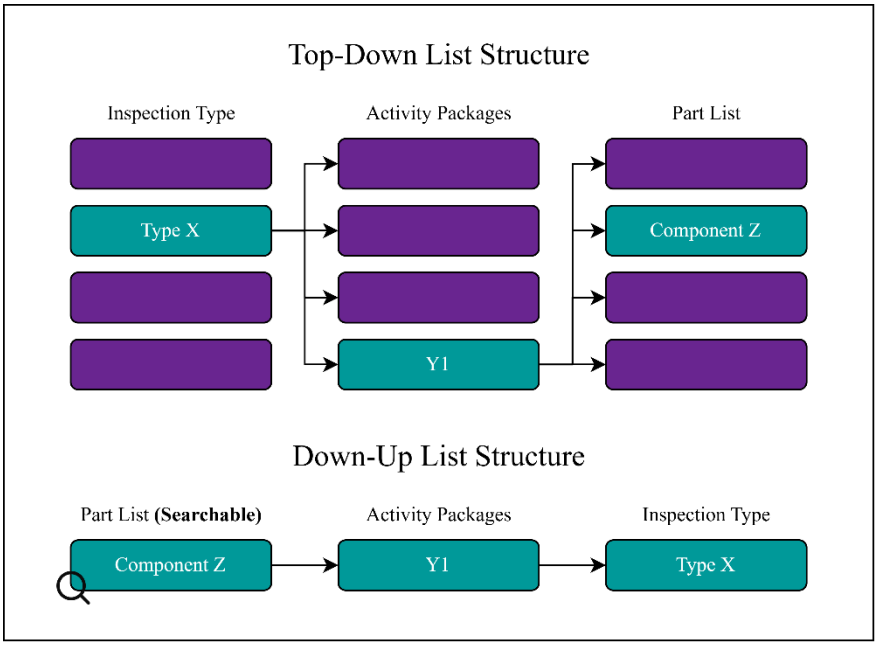

Figure 21 - Illustration of List Structure

7.3 Addressing the Bottleneck of Risk Analysis/Technical Requests

This chapter provides suggestions for improving the efficiency of risk analysis and technical requests, which are identified as bottlenecks in the process of handling late changes in maintenance planning at SE. By addressing these challenges, SE can reduce lead times, improve decision-making, and enhance overall project efficiency. The proposed solutions include both long-term automation initiatives and short-term process improvements.

7.3.1 Long-Term Goal

Automation of Risk Analysis Processes

The automation of risk analysis processes presents an opportunity to enhance efficiency and accuracy within the organization. Currently, more than 20% of technical requests are risk analyses. These often result in long lead times due to their intricate nature and the necessity for precision. A thorough risk analysis is critical, as incorrect assessment can, in extreme cases, cause major damage and personal injury. However, the complexity involved can delay decision-making and project timelines, as determined in Section 6.5.3.

In the short term, some automation has already been implemented, with software tools that assist AEs in finding articles and specific numbers, eliminating the need for manual comparisons between lists. This initial step has helped improve the process, but there is still much room for improvement.

In the long term, integrating artificial intelligence (AI) has the potential to significantly enhance risk analysis processes. This is already evident in data analysis practices used to manage uncertainty in logistics and navigational planning, as demonstrated by companies like DHL and Waze, as discussed in Section 4.3.1. By developing and implementing an automated system that leverages historical data and predictive analytics, SE can evaluate risks with greater speed and accuracy. Such a system could serve as a proactive risk analysis tool, incorporating real-time risk evaluation and scenario analysis. Since AI is not constrained by work capacity, it enables it to process vast amounts of data and generate insights quickly.

The benefits of automating risk analysis are substantial. By reducing lead times in urgent cases, SE can respond more swiftly to potential issues, minimizing disruptions. Additionally, automation would alleviate the manual workload on the Overhaul and Parts department, allowing them to focus on other technical requests.

7.3.2 Short-Term Fixes

Eliminate Unnecessary Technical Requests

Reducing the volume of unnecessary technical requests would enhance operational efficiency. Weekly meetings serve as an effective platform for identifying and catching unnecessary requests before they escalate, but the existing priority system can contribute to unnecessary technical requests. When requests are flagged as high priority, it may lead the individual handling them to overlook their actual relevance and/or necessity. Another common issue is that AEs sometimes fail to consult their assigned senior AE before submitting requests. This oversight can lead to redundant inquiries that could have been resolved through a quick discussion, ultimately wasting time as the recipient of the request disregards it.

To address unnecessary technical requests, SE can implement three key measures. First, introduce a mandatory pre-submission review where AEs consult their senior AE before submitting requests, ensuring unnecessary or redundant issues are resolved early. Second, revise the priority system with stricter criteria for marking requests as “high priority,” requiring clear justification to prevent misuse. Lastly, promote accountability by encouraging AEs to take responsibility for the quality and necessity of their requests. These steps will reduce lead times and improve the overall efficiency of the process.

Furthermore, as described in Chapter 5.1, technical requests are often made because the AE lacks specific information, as it is classified to them. Making certain classified information available can empower AEs to resolve issues independently, reducing the need for technical requests. However, the information is classified for a reason. Therefore, management would need to assess the benefits of the AE being able to work more independently versus the consequences that would unfold if the classified information was leaked. Updating the need-to-know information for AEs will ensure they have access to the most relevant data they typically require. By ensuring AEs has adequate information, SE can minimize unnecessary technical requests and the lead times they entail.

Enhancing Clarity in Technical Requests

To enhance the efficiency and effectiveness of technical requests, the organization could adopt a more specific format that includes comprehensive information in the description. Currently, there is occasionally a mindset among some team members that submitting a technical request equates to passing off responsibility without giving it the necessary thought. This can lead to uncertainty for the recipient, who may struggle to understand the context or requirements of the request.

By adopting a strictly specific format for technical requests, as illustrated in Figure 22, AEs would need to take greater responsibility for the quality of the information they provide, and it would ensure that the next person in line has access to all relevant details. A well-structured technical request should include specific information about the issue at hand, the desired outcome, and any information which would be useful. This lightens the workload for those who must address the request, as they will have a clearer understanding of what is needed. Although the AE would need to spend more time to clarify all details of the request, it would in turn reduce the lead times of technical requests as uncertainty is reduced.

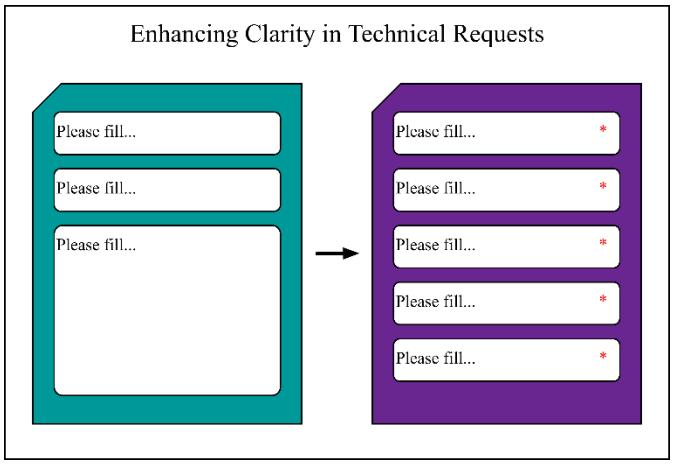

Figure 22 - Illustration of a Clarified Technical Request

Uncertainty within an organization can be harmful for productivity, leading to delays, miscommunication, and frustration among team members. By implementing thoroughness and accountability in technical requests, the organization can mitigate uncertainty and promote a more collaborative atmosphere, ultimately reducing lead times. This aligns with the theoretical perspectives on project management under uncertainty, where flexible plans and contingency buffers are essential for handling unexpected events (Lyon & Popov, 2022).

Limit Technical Request Reports

Limiting the length and timeframe of writing reports for technical requests could improve efficiency and ensure accurate lead time data. Currently, even when a technical request is completed, the process of writing the accompanying report often delays its classification as finished, as described in Section 6.5.3. This creates unreliable data regarding lead times, which can hinder accurate evaluation and further continuous improvement.

To address this issue, reports should be limited to include only the most relevant information. By focusing on the most relevant details and eliminating unnecessary content, the time spent on report writing can be significantly reduced. This idea is illustrated in Figure 23. This approach allows for quicker completion of technical requests and enhances the reliability of lead time data.

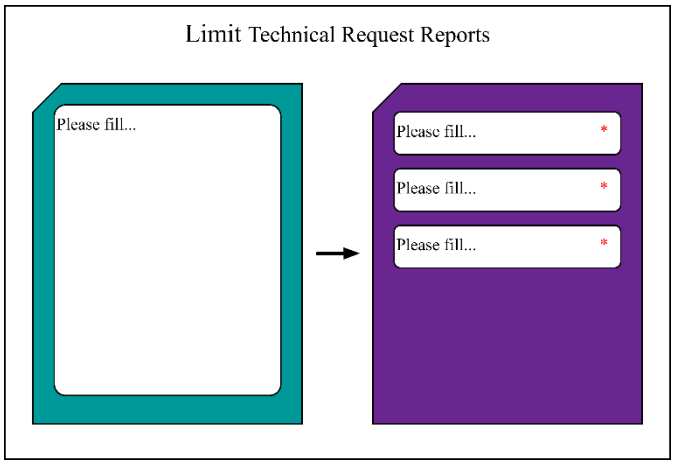

Figure 23 - Illustration of a Limited Technical Request Report

8. Discussion

This chapter discusses the main aspects of the study. It starts by considering the methodological challenges faced, including the quality and ethics of the methodology. Following this, the chapter discusses the results. The generalizability of the findings is then explored, highlighting their relevance beyond the specific context of gas turbines. Finally, the chapter suggests areas for future study, including the investigation of departmental differences and the impact of global guidelines on local processes.

8.1 Methodology Discussion

The methodology employed in this study successfully addressed the purpose of investigating and improving the handling of late changes in maintenance planning. By combining qualitative and quantitative approaches, the study provided understanding of the challenges faced by SE and offered relevant suggestions on improvements. However, certain limitations and challenges emerged during the research process, which are discussed below.

8.1.1 Siemens Energy

One of the key challenges encountered during the study was the limited availability of documentation and data from SE. While the organization provided useful insights through interviews and some technical data, the lack of access to certain records and datasets hindered the scope of the analysis. For example, the initial plan included a more extensive data analysis to identify patterns and inefficiencies in the process of handling late changes in maintenance planning. Data was requested based on measurements from a CTQ-tree, however only data on technical requests and risk analysis was provided. This limitation highlights the importance of strong data management practices within organizations. SE's reliance on fragmented systems and non-searchable formats, such as PDFs, underscores the need for improved digitalization and integration. While the study adapted to these constraints by focusing on qualitative insights and process mapping, a more comprehensive dataset could have strengthened the findings and provided deeper insights into recurring issues.

Despite these challenges, the collaboration with SE personnel proved invaluable. Their willingness to share expertise and participate in interviews allowed the study to capture nuanced perspectives on the maintenance planning process. This underscores the importance of maintaining strong relationships with stakeholders during research, particularly when data access is limited.

8.1.2 Ethics

Ethical considerations were central to the study, as outlined in Section 3.9.1. The research adhered to principles of reliability, honesty, respect, and responsibility, ensuring that all interactions with SE personnel were conducted transparently and professionally. Informed consent was obtained from all interview participants, and their anonymity was preserved throughout the study.

One ethical challenge involved balancing the need for detailed insights with the confidentiality of sensitive organizational data. For example, while technical requests and risk analysis were analyzed, care was taken to avoid disclosing proprietary information or compromising SE's competitive position. This required a careful approach to data presentation, ensuring that findings were generalized and anonymized.

The study also emphasized the importance of respecting the time and expertise of SE personnel. Interviews were conducted in a structured yet flexible manner, allowing participants to share their perspectives without feeling pressured or constrained. This approach not only enhanced the quality of the data collected but also reinforced the ethical commitment to valuing stakeholder contributions.

8.1.3 Quality of Methodology

The quality of the methodology was evaluated based on the principles of validity, reliability, and objectivity, as discussed in Section 3.9.2. The study's explorative approach allowed for flexibility in addressing emerging insights, ensuring that the research remained relevant and comprehensive. Multiple data collection methods, including interviews, process mapping, and thematic analysis, provided a well-rounded understanding of the research problem.

The iterative refinement of the process map and interview questions demonstrated a commitment to methodological quality. For example, the validation of the process map by SE personnel ensured that the findings were grounded in the reality at SE. Similarly, the use of tools like PFMEA and the Impact-Effort Matrix added structure to the analysis, enabling the identification of key areas for improvement. However, the time constraints of the research limited the practical implementation of suggested improvements, leaving their feasibility and impact to be assessed by SE. Another methodological limitation is the arguably small sample size used in the interviews, which, while justifiable for this type of study, still significantly impacts the results.

Overall, the methodology was adaptable, successfully addressing the research questions despite certain limitations. The combination of qualitative and quantitative approaches, along with ethical and quality considerations, ensured that the study provided meaningful insights and relevant suggestions on improvements.

8.2 Result Discussion

The results of the study were satisfactory and aligned with initial expectations, identifying and providing insights into the challenges of handling late changes in maintenance planning. However, the study's reliance on qualitative data and limited access to comprehensive datasets highlighted areas for further exploration, particularly in quantifying the impact of proposed solutions.

8.2.1 Effect of Varying Levels of Experience

The ability to handle late changes effectively is heavily influenced by the experience level of personnel. While experienced AEs and PMs can rely on their expertise to navigate complex scenarios, less experienced staff often face greater challenges, requiring more time and resources. This proved apparent during the interviews, as more experienced AEs found some issues irrelevant, when less experienced AEs struggled with these issues daily.

The varying levels of experience affected the result as the different experience levels had to be taken into consideration when formulating improvements. The improvements were aimed at enhancing the workflow in a general way, not being biased toward a certain group. Therefore, certain improvements may seem redundant to personnel with higher levels of experience but will improve the situation for personnel with lower levels of experience.

8.2.2 Reliance on Qualitative Data

The reliance on qualitative data due to limited access to quantitative records introduced a degree of subjectivity into the findings. Although this was addressed by triangulating insights from various sources, the study would have been strengthened by the inclusion of more quantitative data. This would have added greater objectivity to the result, therefore increasing the study's overall reliability.

8.2.3 Finding the Right Balance Between Standard and Custom Plans

Another challenge in maintenance planning is balancing standard processes with the need to customize for specific customers or turbine models. Standardized plans save time and reduce errors, but they may not always fit unique customer needs. For example, older turbines like the SGT-600 often require special attention due to their history of repairs and upgrades.

This study aimed to provide insight into maintenance planning and how late changes affect it for general SGT-600 cases. This means that some of the analytical findings and conclusions may be too generalized to be applicable for highly customized machines.

8.2.4 The Human Side of Maintenance Planning

While technology plays a big role, the human element in maintenance planning is equally critical, particularly when it comes to judgment and decision-making. Different people, whether they are AEs, PMs, or other stakeholders, will often interpret the same parameters or data in varying ways, influenced by their experiences, perspectives, and priorities. This variability is a natural part of the human side of planning and can lead to diverse approaches to problem-solving but also mistakes as a result of limited time.

These differences in judgment could have impacted the results of this study as varying interpretations of urgency, risk, or resource allocation may lead to inconsistent conclusions or conflicting recommendations.

8.3 Generalizability

The findings of this study have broader implications beyond the specific context of gas turbines. Maintenance planning challenges, such as handling late changes by improving data availability and improving communication are common across industries that rely on complex machinery and systems. The study's focus on standard problems and standard solutions demonstrates its applicability to other sectors that rely on maintenance planning.

Industries like manufacturing, logistics, and healthcare share similar needs for efficient planning processes to minimize downtime and ensure operational reliability. For example, the study's emphasis on improving data management and integrated systems can be applied to sectors where fragmented data slows decision-making and creates inefficiencies. Similarly, the importance of structured workflows and clear communication highlighted in this study is relevant for any organization managing multi-stakeholder projects.

In conclusion, the findings of this study are not limited to SE or the energy sector. They provide insights that can be adapted to various industries to improve maintenance planning and operational processes.

8.4 Future Studies

This chapter aims to identify additional areas for future research that could offer further insights to SE, ultimately supporting the ongoing improvement of its operations.

8.4.1 Evolution of the Energy Industry

The energy industry is changing rapidly, driven by advancements in technology and evolving customer expectations. For instance, the growing demand for renewable energy systems and innovative turbine materials will influence maintenance planning in the near future. Additionally, new regulations promoting sustainability and renewability are continuously being introduced. Since gas turbines rely on non-renewable fuels, SE may need to adjust its operations to align with shifting market demands. While these changes could make some tasks easier, they are also likely to bring new challenges that require adaptation and innovation.

To stay ahead, SE should invest in developing their maintenance planning practices. This could start in thinking about what the industry might look like in five or ten years and preparing for those changes now.

8.4.2 Learning from Other Industries

There is much to learn from how other industries handle similar challenges. For example, logistics companies use data analysis and scenario planning to manage uncertainty in the supply chain which could be translated to project management practices. Similarly, delivery services and navigational planning use optimization algorithms and predictive models to adjust delivery routes in real time, ensuring on time delivery even when unexpected events take place. By studying these industries, SE could find new ways to improve its maintenance planning. Collaborating with experts from other fields could also bring fresh ideas and innovative solutions.

8.4.3 Global Initiatives and Guidelines

Global company initiatives often aim to standardize processes and ensure alignment with corporate goals, but they can sometimes hinder local innovation and adaptability. For SE, adherence to global guidelines may limit flexibility in addressing region-specific challenges, such as environmental conditions or regulatory requirements. Future research could explore how to balance global standardization with local needs, potentially through hybrid frameworks that integrate best practices with regional customization.

9. Conclusion

The purpose of the study was to describe and analyze the maintenance planning process and how it can be improved. This purpose was divided into three research question, and chronologically answered in Chapters 5, 6 and 7.

RQ1: How is the maintenance planning process affected by late changes?

Late changes significantly impact the maintenance planning process at SE by introducing disruptions that require dynamic adjustments and reallocation of resources. To answer this question, the first step was to look at what the causes of late changes are. The result is described by six recurring causes for late changes to the scope: *part issues, tools/instruments, wrong scope from beginning, internal demands, external demands* and *personnel.* Through the identification of causes of late changes, a reference to correlate the impact of late changes was acquired. Late changes lead to extended outages, increased costs, and potential delays in project completion. The project team must quickly reassess the situation, update activity lists, and communicate changes to all relevant stakeholders, which can be time-consuming and complex. Additionally, late changes can result in the need for additional risk analysis and modifications to the maintenance scope, further complicating the process. Overall, late changes create a negative domino effect, affecting various aspects of the maintenance planning process and reducing overall efficiency.

RQ2: What parts of the maintenance planning process are most time-consuming to handle when there are late changes in maintenance planning?

The most time-consuming parts of the maintenance planning process at SE, when handling late changes, are risk analyses, inter-departmental communication and decision-making for potential outage extensions, as seen in Figure 24. Risk analyses have a long lead time and can take more than three months to complete, often causing delays. Communication issues arise from the need for extensive coordination among stakeholders, including AEs, PMs, and logistics personnel. Additionally, the decision-making process, especially for rescheduling or extension of on-site time, is a difficult step in the process. The dependencies associated with these decisions create complexity which makes this a demanding step in the process. Collectively, these factors contribute to inefficiencies and increased project costs.

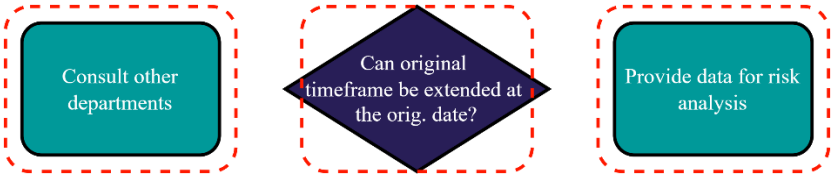

Figure 24 - Time-Consuming Process Steps (in conclusion)

In the undertaking of answering RQ2, a process map of the handling of late changes in maintenance planning was created. It provides a clear overview of all aspects in the process of handling a late change in maintenance planning, allowing for the identification of bottlenecks in the process and improvements related to specific activities or decision points.

RQ3: How could the handling of late changes in maintenance planning be improved, with regard to data and process management?

To improve the handling of late changes in maintenance planning at SE, refinements in data and process management are necessary. To tackle the problem areas, as identified through the time-consuming process steps as seen in Figure 24 and the Impact-Effort matrix, improvement suggestions have been divided into three areas: collaboration and communication between departments, data management and availability, and risk analysis/technical requests. For each area, short-term fixes and long-term goal(s) have been proposed.

The short-term fixes focus on improving immediate efficiency and collaboration through clearer communication, standardized processes, better data accessibility, and more efficient technical requests. These suggestions aim to address current bottlenecks and reduce lead times with less need for investment.

The long-term goals, on the other hand, outline transformative changes such as deeper interdepartmental collaboration, automation of complex processes, and creation of integrated platforms. These suggestions emphasize a strategic commitment to advancements that, while requiring greater time and investment, have the potential to deliver substantial gains in the ability to handle late changes in maintenance planning.

Concluding this thesis, the study has fulfilled its purpose and answered the research questions. The findings of the study underscore the importance of addressing both process inefficiencies and data management challenges in maintenance planning. Specifically, the study reveals that late changes in maintenance planning create a domino effect of inefficiencies, not only disrupting operations but also placing significant strain on personnel. Addressing these bottlenecks through both immediate fixes and long-term initiatives will improve handling of late changes. The findings of this study are not limited to the studied organization or the energy sector as they provide insights and propose suggestions for improvement that can be adapted to maintenance planning in various industries and operational processes.

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Appendix A - Interviews

In Table A.1 all interviews held during the study are listed. A.1-interviews are introductory unstructured interviews. A.2 and A.3-interviews are semi-structured interviews. A.4-interviews are unstructured interviews.

Table A.1 - Interviews

Code	Location	Interview type	Interviewee	Date
A.1.1	On-site	Unstructured	AE Manager	2025-01-29
A.1.2	Microsoft Teams	Unstructured	Systems Architect	2025-02-05
A.1.3	Microsoft Teams	Unstructured	AE	2025-02-05
A.1.4	Microsoft Teams	Unstructured	Senior AE	2025-02-10
A.2.1	Microsoft Teams	Semi-structured	AE Manager	2025-02-13
A.2.2	Microsoft Teams	Semi-structured	AE	2025-02-14
A.2.3	Microsoft Teams	Semi-structured	AE	2025-02-14
A.2.4	Microsoft Teams	Semi-structured	AE	2025-02-14
A.2.5	On-site	Semi-structured	AE	2025-02-17
A.3.1	Microsoft Teams	Semi-structured	Senior PM	2025-02-25
A.3.2	Microsoft Teams	Semi-structured	PM	2025-02-26
A.4.1	Microsoft Teams	Unstructured	Life Management Expert	2025-04-08
A.4.2	Microsoft Teams	Unstructured	AE	2025-04-08
A.4.3	Microsoft Teams	Unstructured	Senior AE	2025-04-10
A.4.4	Microsoft Teams	Unstructured	R&D Manager	2025-04-16
A.4.5	Microsoft Teams	Unstructured	R&D Manager	2025-04-16
A.4.6	Microsoft Teams	Unstructured	AE Manager	2025-04-16

A.1 Introductory Unstructured Interviews (First Set)

In the first four interviews the purpose was to gain an understanding on the subject and related areas for this thesis. Questions were made up on the spot during the interview, and for the most part the interviewee presented their work and helped us understand their perspective on the problem that this study is based on.

A.1.1

Purpose: Understand the role of the application engineer.

- **What does an Application Engineer do?**

An AE develops and manages maintenance plans, ensures compliance with technical guidelines, and acts as a technical liaison in meetings. They coordinate technical issues with support from various departments and oversee the technical scope and support before, during, and after inspections, which includes handling unplanned events.

- **What is your view on late/unforeseen events happening in maintenance planning?**

They usually come from PMs/salespeople who do not fully understand the technical requirements. This can cause significant issues when planning maintenance activities that should not have been accepted initially. As an AE, I would like the scope of the maintenance plan to freeze 3-6 months prior to the inspection date.

- **Which type of data causes the most issues?**

The most problematic data is the data which is hard to find and missing from the place where it should be. This causes additional and partially unnecessary work to find the information in for example product maps and lists of interchangeable parts in PDF format that would benefit from being searchable and interactive. Another data related issue is classification data which is often incomplete and not centralized. Additionally, top-down loaded lists that require filtering through each part instead of starting with the known part needing replacement complicate the preparation of disassembly and assembly.

A.1.2

Purpose: Gain insight of data flow, based on the data flow map provided week 5, 2025.

- **What do you work with?**

I work at the as a system architect at the maintenance department, specifically within digital integration. We mainly work with data analysis and support systems, such as the AED. AED is a system that aims to collect all necessary data for the AE in one place.

- **Describe the map of data flow for the application engineer.**

The map was created with purpose to understand the complexity and all the dependencies in the data flow of the maintenance planning process. It mainly concerns the AEs use of the AED and how data is retrieved, created or refined in the activities of the planning. Information to the AED is uploaded every night.

- **Are there certain data/process steps/software programs that you know often cause problems?**

Yes, there are two problems that I often come across. Firstly, when activities and reserve parts are made to latest standard for that machine type from “nysidan”, but very rarely the machine on site match this standard. This causes a lot of dissimilarities and problems in keeping information organized. Other than that, an ongoing problem is that a lot of information is kept only in documents that cannot be searched and therefore the information is harder to access.

- **What is a common late change scenario and how is it handled?**

One scenario is that there is a planned inspection, and the scope for what needs to be done is predetermined. As the inspection is conducted, it is determined that maintenance is needed urgently. This means that the scope needs to be changed, and sufficient resources needs to be allocated, such as maintenance workers with expertise for that type of maintenance. The AE may for example use SALSA, SAP, TAGE and Manpower to determine the new plan.

A.1.3

Purpose: Discuss AED and ask general AE questions.

- **Are there certain data/process steps/software programs that you know often cause problems?**

There are multiple things. For one, reports are not always as they should, this is partially due to different standards in time, but also that they have not been updated. Furthermore, there is a lack of consistency when it comes to the transferal of experience and handover of machines to colleagues, for example when someone retires.

Then there is the issue of finding data that is missing in the commonly used programs. It could be for example that a date for when maintenance was performed is missing. Migration between programs causes data to go missing so it would be a good idea to check the evolution of the standard of mechanical reports/records, this could indicate why certain data is not readily available.

A common issue is that people often fail to update information according to the guidelines, leading to significant problems when this data is needed for decision-making.

- **What could be improved regarding the AED?**

There is only data from 2020 onward. Having all the information and being able to only use one system would improve the workflow.

- **How is a late change usually handled? In terms of responsibility within the project team and use of standardized processes?**

There is a workflow in place, but not everyone knows it, especially the sales personnel.

A.1.4

Purpose: Discuss late changes in the maintenance process.

- **Do you have a structured process map for handling unforeseen events in planning?**

We do not have a specific process map for unforeseen events in planning. We have processes for unforeseen events outside of planning, but we assume everything will go as planned, which is not always the case.

- **Are there certain (data/process steps/software programs) that you know often cause problems?**

Challenges include dealing with outdated or incomplete data, especially for older machines, such as the SGT-600. A particularly time-consuming process is the matching of parts lists in the RLvsB-Spec system, which matches standard parts lists with actual machine configurations.

Another thing is the Remote Online Check (ROC) which should happen about 3 months before inspection. For this activity, which aims at streamlining the on-site inspection by preemptively identifying and planning for necessary repairs or replacements, there can sometimes be issues with data that has either not been received or for some reason is unavailable. Furthermore, recommendations provided in the ROC report can sometimes be unclear, leading to potential misinterpretation potentially causing confusion during the inspection.

- **How is a late/unforeseen change usually handled?**

When a late or unforeseen change occurs, the team conducts a risk analysis to evaluate the impact on the maintenance schedule and equipment. Key data, such as operational hours and affected components, are analyzed. If parts or tools are unavailable, logistics addresses delivery issues, and project leaders communicate with customers to adjust plans. AEs assess risks and suggest alternatives. The scope of work may be adjusted, and the activity list is revised to reflect the updated plan, ensuring flexibility and maintaining the integrity of the maintenance schedule.

- **In what instances is the scope of the inspection changed?**

Changes to the scope may arise, for example, due to the AE specifying the wrong scope, changes in our lifespan documents, new customer requirements, lack of personnel, or tools/instruments/materials. Sometimes, the change means that we need to consider the possibility of postponing the inspection (this is when we need to initiate a risk analysis). If the sellers manage to sell any additional scope, we also need to include that. The same applies after the completed ROC, as the scope may need to be updated.

- **What does the scope of the inspection consist of?**

The scope includes noble parts with lifespan limitations, consumables, tools, instruments, activity lists, report templates, technical documentation, assembly folders (relevant drawings, lists, etc., so that the site personnel have all the information they need to perform the job). It

also includes reviewing recommendations given in previous reports, checking for any open cases in Sales Force, open error reports, or technical requests. We need to review if there are service products that may be appropriate to introduce (for free or to sell) during the inspection. We also need to write technical requests to develop templates for PEC testing and to have the ROC performed in cases where it is included.

- **What changes to the scope are the most demanding to solve?**

The most demanding aspect for the AE is probably when we have additional sales to incorporate, as this can potentially affect all steps (parts, report templates, activity lists, documentation), and we often need to write technical requests to create a machine-adapted scope. If the sales are also delayed, then all steps become urgent to complete.

- **Which types of problems/scenarios/causes for late changes to maintenance planning are the most demanding to solve?**

The most demanding problems include logistical issues such as unavailable parts, tools, or personnel. These issues often require rescheduling, risk analysis and the initiation of a "technical request" which can take up to 3 months. Additionally, unexpected customer requests to change the scope of work due to their operational constraints can be challenging.

A.2 Semi-structured Interviews (Second Set)

In the second set of interviews, five semi-structured interviews were held with the purpose to gain further information on different causes to change the scope and identifying areas for improvement in process and IT-related issues. A short introducing explanation was given, and questions were prepared before the interviews and asked to all interviewees in a similar way.

This summary captures the key concepts from the interviews by generalizing the specific cases while focusing on the main challenges, actions, and desired improvements in data accessibility and process related to the scope of the study.

Interviewees:

Application Engineer Manager (1): A.2.1

Application Engineer (4): A.2.2, A.2.3, A.2.4, A.2.5

Explanation: Our study will evaluate how unforeseen and/or late changes are administratively handled and identify what could be improved in this area? Furthermore, our study aims to see if there could be combinations of process and IT improvements which have a significant impact on SE's ability to efficiently re-plan maintenance in instances where maintenance cannot be executed according to the original plan.

Question 1: We have identified these recurring causes for changing the scope of an inspection (seen in Figure 25), do you agree with it? How would you rank these causes by the time and effort they require to resolve, and can you think of any additional causes?

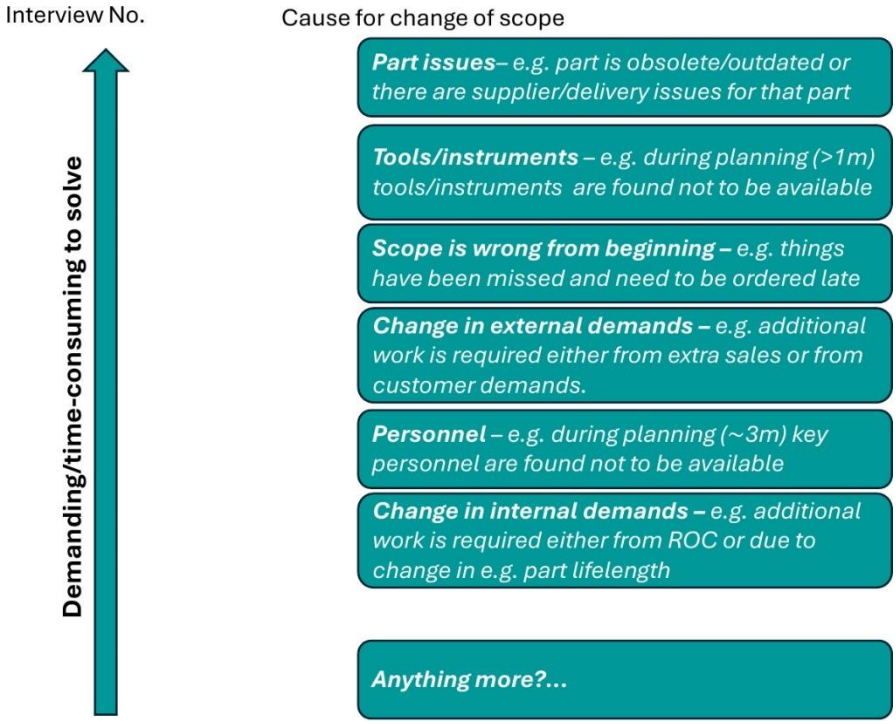

Figure 25 - Rating of Causes Activity

Across the interviews, the rating of factors by the time and effort required by AEs varies to some degree. However, the common thread is that changes driven by external requirements or late-discovered part issues (such as obsolescence in parts) and personnel shortages are most demanding. In contrast, issues like tool/instrument availability, but also part issues if identified early, tend to be less time-consuming. Scope issues are usually easy to fic as the most typical case can simply be added to the activity list with further actions required. In essence, changes related to unforeseen circumstances in customer requirements and internal misalignment related to parts and personnel generally rank as the most demanding and time-consuming challenges for the AE.

1. Part Issues:

Problems with obsolete or outdated parts, or supplier issues, are common. If parts become obsolete, they should be flagged in the SAP material master, and a replacement should already be identified. However, delivery issues from suppliers, especially for long-lead-time components, can lead to scope changes if parts cannot be delivered on time. This issue is generally manageable if identified early and handled through communication with suppliers.

2. Tools and Instruments:

Availability issues of necessary tools and instruments can arise, but these are typically less demanding to resolve. If tools are unavailable, PMs often negotiate with customers to use their tools or find replacements. This problem is less time-consuming compared to others.

3. Scope Set Wrong Initially:

If the initial scope of inspection is incorrect or incomplete, it can lead to significant rework and delays. This issue can stem from poor handovers between AEs or missing information due to personnel changes. While it can be quickly fixed once identified, it can have a substantial impact if critical tests cannot be conducted as planned.

4. Changing External Requirements:

Customer demands are the most common cause of scope changes, particularly in regions like Latin America where intermediaries may promise customers changes without consulting the main office. These changes are time-consuming to resolve as they often require re-planning the inspection and managing customer expectations.

5. Personnel Availability:

The availability of key personnel can impact the scope if the right people are not available. This issue is significant but manageable with proper planning. In urgent cases, personnel from other regions can be brought in, though this involves significant administrative work and costs.

6. Internal Requirements:

Changes due to internal checks or updates can vary in time consumption. Simple additions are easy to manage, but significant changes, especially those affecting core parts, can be very time-consuming as they require additional instruments and extended on-site time.

Question 2: Imagine that the most demanding case you rated happens, for example, an unexpected upgrade (such as from 600A1 to 600A2) is suddenly sold 8 months ahead of a planned outage. How do you act on this situation? Walk us through your activities and the active decisions you have to make.

When an unexpected change happens, the first step is to determine who, or perhaps which department should handle the scenario. Once this responsibility is clarified, the team reviews the planned inspection scope and looks at what aspects are affected by the change. This typically involves carefully checking which parts, tools, instruments, and documentation are affected.

The process can be very different, but some of the activities that almost always happen includes looking at EOH and creating or updating various lists (materials, tools, instruments, activities). In several interviews the respondents mentioned discussing the matter with key stakeholders, such as PMs, delivery coordinators. If the change is somewhat extensive the customer is generally consulted to decide whether the change can be accommodated within the existing schedule or if a rescheduling of the outage is required. For more complex scenarios, the resolution may involve risk analysis and technical requests where more actors are involved in finding a solution to the change.

Ultimately, by evaluating technical impact, resource availability, and customer expectations, the team either adjusts the scope while continuing with the scheduled inspection or opts to reschedule to ensure safety and quality.

Question 3: What data is typically most important when changing the scope?

The data deemed critical when considering a scope change revolves around detailed component and machine information. Most interviewees highlighted the importance of having access to accurate and up-to-date engine or component life data, such as equivalent operating hours, historical maintenance records, and the relevant B-specs. This information is used not only to validate the health of parts but also serves as a key input in risk analyses when making decisions on scope modifications. Additionally, inspection reports that capture part condition, as well as detailed records from preceding maintenance or refurbishments, have been mentioned as essential to ensuring that any change in scope is appropriately informed. The overall technical condition and history of the machine, often stored in legacy systems like SAP or within PDF documents, is central to these decisions.

Question 4: In general, could you think of certain data which could be digitalized or made more accessible to facilitate decision-making? How?

A recurring theme across the interviews is the need for better digital integration of data to support faster and more informed decision-making. Many respondents suggested that key datasets, for example historical refurbishment records, maintenance logs, and accurate, machine-specific B-specs, should be centralized in an accessible and user-friendly database or dashboard. Some proposed creating standardized lists that translate contractual requirements into technical specifications, which could help avoid misinterpretations or delays when scope changes become necessary.

In addition, data related to variant management, interchangeable parts, and the technical details of each component (down to a detailed parts hierarchy) would greatly streamline the process if made digitally available and more navigable and interactive. The overall push is towards replacing scattered PDF documents and siloed databases with integrated, real-time digital systems that ensure all stakeholders have the most up-to-date information at their fingertips.

Question 5: Are there any other specific problems in data/process steps/software programs that you know often cause issues?

Finally, several interviewees pointed to systemic issues in data management and process integration that contribute to difficulties in scope changes. One common theme is the challenge arising from the lack of integration between different departments. A commonly mentioned example of this is the disconnect between sales, engineering, and project management, which can result in miscommunication or incomplete data capturing.

Another specific problem is the difficulty in accessing comprehensive mechanical records from legacy systems. For example, because critical information is buried in PDFs or non-interactive PLM systems.

Furthermore, insufficient traceability of parts related to serial numbers and refurbishment histories was mentioned as a problem. Lastly issues related to outdated B-Specs as a result of people not validating or updating the B-Spec as per guidelines, either because of poor practice or because of budgetary reasons. Overall, improving the connectivity and validation steps

between these software programs and internal data repositories is seen as critical for reducing delays and errors during inspections or upgrades.

A.3 Semi-structured Interviews (Third Set)

In the third set of interviews, two semi-structured interviews were held with the purpose to gain a separate perspective to the one from the AE on the process flow in the handling of late changes. The role of PM was selected after discussion with supervisor at SE. Similarly to the second set, a short introducing explanation was given, and questions were prepared before the interviews and asked to all interviewees in a similar way.

This summary captures the key concepts from the interviews by generalizing the specific cases while focusing on the main challenges, actions, and desired improvements related to the scope of the study.

Interviewees:

Senior Project Manager (1): A.3.1

Project Manager (1): A.3.2

Explanation: *Our study will evaluate how unforeseen and/or late changes are administratively handled and identify what could be improved in this area? Furthermore, our study aims to see if there could be combinations of process and IT improvements which have a significant impact on SE's ability to efficiently re-plan maintenance in instances where maintenance cannot be executed according to the original plan.*

Question 1: What responsibilities are included in the project manager role?

The role of a (O)PM involves overseeing the entire project from start to finish. This includes initializing the planning, managing inspections and overhauls, ensuring that the project scope is clear, and that all necessary materials and manpower are secured. The PM is responsible for coordinating with various team members, including the CPM, SM, CCM, LPM and the AE. They also handle tools and instruments, maintain communication with the customer, and ensure that all aspects of the project are managed effectively.

Question 2: What do you think are some examples of reasons why unforeseen/late changes occur? Which is the worst?

Unforeseen or late changes can occur due to several reasons. Poor planning or lack of communication with the customer can lead to unexpected changes. Last-minute technical bulletins or safety notices that require immediate attention can also cause delays. Quality issues within components, such as defects in the turbine, and logistical issues with parts, tools, and instruments are common. Additionally, human error, such as missing items or miscommunication, and delays in securing manpower can contribute to unforeseen changes.

Question 3: Regarding the various causes, we wonder if you can describe how an overall and generalized solution process, with regard to activities and decisions taken to resolve the situation, might look like? (e.g. how do you decide if it needs to be rescheduled, if you need to change the scope, and if you change the scope what parts are needed etc.?)

When an unforeseen change occurs, the team must first analyze the impact, including the need for additional parts, tools, and personnel. Decisions are made based on the availability of resources and the feasibility of implementing the changes within the existing schedule. Risk analyses are conducted to evaluate the technical implications of any delays or changes. The team contacts planners, updates instruments and materials, and communicates with the customer and regional teams. They also consider the customer's perspective, such as how many hours the machine has operated and whether it can continue running if the inspection is postponed.

Question 4: Are there specific decisions that can be especially difficult to make for the AE, Project Manager or Project Team in general?

Balancing the need to reschedule maintenance versus changing the project scope can be particularly challenging. Ensuring that all necessary resources are available to implement changes without causing further delays is another difficult decision. Risk analysis and scenario planning, such as deciding whether to replace corroded parts, involve evaluating material availability, costs, and the impact on the project timeline. These decisions require careful consideration of various factors and potential outcomes.

Question 5: In general, could you think of certain data which could be digitalized or made more accessible when making decisions?

Having comprehensive and accessible data is important for making informed decisions. A dashboard that integrates data from various systems, such as SAP and Salesforce, could provide a holistic view of the project status and any new changes. Data on machine operation hours, material availability, and tool/instrument availability could be better digitalized. This would help in making more informed decisions quickly. Improving on historical data and lists could also support decision-making processes.

Question 6: Are there any other specific problems in data/process steps/software programs that you know often cause issues?

Managing multiple systems and ensuring that all necessary data is available and up to date can be complex. Better integration and visualization tools are needed to help project teams manage changes more effectively. Communication and coordination among various stakeholders can be challenging, especially during rescheduling. Ensuring that all parties are informed and synchronized is critical but often difficult. Additionally, the time required to refurbish parts is often longer than expected, which can cause further delays.

A.4 Unstructured Interviews (Fourth Set)

In the fourth set, described in Section 3.5.4, six participants with different roles were interviewed with the purpose of brainstorming improvements suggestions for the improvement areas determined in Chapter 7. This chapter presents a list of all suggestions which were brainstormed during the interviews.

Interviewees:

Life Management Expert (1): A.4.1

Application Engineer (1): A.4.2

Senior Application Engineer (1): A.4.3

Research and Development Manager (2): A.4.4, A.4.5

Application Engineer Manager (1): A.4.6

Below are all the suggestions proposed by the interviewees, divided in the three areas for improvement.

1. **Collaboration and Communication Between Departments**

    - **Clarify Responsibility for Late Changes**
        - Clearly define and communicate who is responsible for approving and resolving late changes.
        - Establish organizational guidelines for decision-making in the late change process.
        - Ensure that Application Engineers (AEs) are promptly informed of project changes and required risk analyses.
        - Assign the most suitable and flexible personnel to resolve issues, promoting a dynamic and adaptable approach.
    - **Improve Mutual Understanding**
        - Address different interpretations of problems by understanding various perspectives.
        - Standardize what constitutes an acceptable solution and prioritize solution types (strategic vs. practical).
        - Develop standard solution alternatives to create a shared view of acceptable outcomes.
        - Organize knowledge-overlap workshops to bridge gaps between departments.
    - **Enhance Prioritization and Response Times**
        - Implement clearer prioritization of cases to distinguish urgent from less critical messages.
        - Develop mechanisms to highlight the urgency and importance of different requests.

- **Structured Communication for Urgent Tasks**
  - Establish regular, structured meetings (e.g., between OPM and AE) to discuss technical issues, especially when urgent tasks arise.
- **Define Roles and Responsibilities**
  - Clearly define the division of responsibility between OPM and AE for handling late changes, particularly during inspections.
  - Assign LPM to handle serial number changes.
  - Involve sales personnel in discussions about responsibilities during planning kick-offs.
- **Guidelines for Feasibility Discussions**
  - Create guidelines for discussing the feasibility and reasonableness of late changes.
  - Encourage early estimation of time requirements for changes.
- **Centralized Communication Platform**
  - Implement a centralized communication platform (possibly integrated with AED) for all project stakeholders, enabling real-time messaging, document sharing, and project updates.

2. Data Availability and Management

- **Centralized Data Management**
  - Develop a centralized, user-friendly database integrating data from various systems (e.g., SAP, Salesforce) for a holistic project overview.
  - Implement advanced data indexing and search capabilities to improve data accessibility and decision-making.
- **Digitization and Standardization**
  - Digitize historical records (e.g., mechanical records) and use AI to extract data from old reports.
  - Standardize data formats and communication, especially for parts installed by field service, to reduce information distortion.
- **Improve Data Flow and Integration**
  - Minimize the number of steps data must travel to reduce errors and delays.
  - Improve the interface/checklist for tracking the status of all project stages.
  - Enable data extraction from multiple software sources for comprehensive project assessment.
- **Database Structure and Tools**
  - Evaluate and improve current database structures (e.g., Snowflake, TAGE) and address deficiencies.
  - Consider implementing a data lake architecture for scalable, real-time data storage and analytics.
- **Data Governance**
  - Expand data governance to include commercial data (e.g., customer data), not just technical data.

- Establish clear ownership and synergy between different applications and development projects.

- **Forecasting and Predictive Tools**
  - Integrate forecasting for replacement of critical parts into AED to support AEs.
- **Leverage Synergies**
  - Identify/utilize synergies between different applications to maximize efficiency.
  - Assign someone to oversee synergies between applications.

3. Handling of Technical Assignments and Risk Analysis

- **Automate and Streamline Risk Analysis**
  - Develop automated tools for risk analysis using historical data and predictive analytics.
  - Implement risk management software to automate identification, assessment, and mitigation of risks.
- **Improve Technical Request Quality**
  - Encourage AEs to write more detailed and specific technical requests, including part numbers and relevant details, to facilitate handling.
  - Reduce unnecessary technical requests by improving internal communication and knowledge sharing (e.g., weekly meetings to review and dismiss unnecessary requests).
- **Reduce Manual Work**
  - Increase interactivity and integration with existing data systems to minimize manual data entry.
  - Include more machine metadata (e.g., maintenance programs, fuel type, system configurations) in technical requests.
- **Risk Management Structure**
  - Establish a dedicated risk management task force or review committee with cross-functional expertise for regular risk assessments and mitigation planning.
  - Create an interactive risk analysis dashboard for real-time insights and scenario modeling.
- **Transparency and Communication**
  - Provide customers with time estimates for technical requests after a few days for increased transparency.
  - Ensure AEs communicate reasons for urgent requests and short timeframes.
- **Reduce Lead Times**
  - Use tools like PowerBI to quickly retrieve tailored data for technical assignments, reducing lead times.
- **Promote Ownership and Collaboration**
  - Encourage a culture of ownership over technical assignments and encourage direct, face-to-face communication to enhance collaboration.
- **Reduce AE Dependency on Other Departments**
  - Explore ways to minimize the need for AEs to seek help from other departments.