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Analyzing Product Quality Issues in the Marine Engine Industry

A DMAIC Case Study

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ABSTRACT:

Product quality is a critical determinant of competitiveness and long-term success in industrial manufacturing. Increasing quality requirements with growing products, processes, and system complexity create challenges for organizations to overcome. This is particularly evident in industries that produce complex engineering products, such as marine engines. In this context, product quality issues can result in substantial financial losses, operational disruptions, safety risks, and reputational damage. Despite established quality management systems and requirements, recurring product quality issues remain persistent challenge in the marine industry. This highlights the need for more systematic and data-driven approaches to quality improvement.

This research investigates product quality issues in the marine engine industry through a case study conducted at a global manufacturing company. The research aimed to identify the most significant categories of product quality issues, analyze their root causes, and propose improvement suggestions to prevent their recurrence. The study applied the Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) methodology as a structured framework for quality improvement. Both quantitative and qualitative data were utilized. Product quality issue data was analyzed using categorization and Pareto analysis to identify the most significant defect categories and subcategories. In addition, root cause analysis techniques, including the fishbone diagram and the 5 Whys method, were applied to selected priority areas to gain deeper insight into underlying causes.

The findings of this research indicate that recurring product quality issues are not solely driven by technical factors but are strongly linked to human and organizational factors such as unclear responsibilities, insufficient documentation practices, communication gaps, and challenges in cross-functional collaboration. These findings suggest that effective quality improvement in complex industrial environments requires the integration of quantitative quality data with qualitative managerial insights. The study contributes to filling identified gaps in the literature as well as providing improvement actions towards the case company and the overall marine engine industry. The research also offers recommendations for further research, creating the opportunity to expand the sample and the significance of the study.

KEYWORDS: product quality, quality management, quality improvement, marine technology, manufacturing industry

VAASAN YLIOPISTO**Tekniikan ja innovaatiojohtamisen akateeminen yksikkö****Kirjoittaja:** Iina Elorinne**Tutkielman otsikko:** Analyzing Product Quality Issues in the Marine Engine Industry: A DMAIC Case Study**Tutkinto:** Diplomi-insinööri**Ohjelma:** Industrial Systems Analytics**Ohjaaja:** Jouni Juntunen**Vuosi:** 2026 **Sivumäärä:** 101

TIIVISTELMÄ:

Tuotteiden laatu on ratkaiseva kilpailukyvyyn ja pitkän aikavälin menestyksen määräävä tekijä teollisessa valmistuksessa. Kasvatavat laatuvaatimukset, tuotteiden, prosessien ja järjestelmien monimutkaisuuden kasvaessa, luovat organisaatioille haasteita. Tämä näkyy erityisesti monimutkaisten teknisten tuotteiden, kuten laivojen moottoreiden, valmistavilla teollisuudenaloilla. Tässä yhteydessä tuotteen laatuongelmat voivat johtaa merkittäviin taloudellisiin tappioihin, toiminnan häiriöihin, turvallisuusriskeihin ja mainehaittoihin. Vakiintuneista laatujärjestelmistä ja -vaatimuksista huolimatta toistuvat tuotteiden laatuongelmat ovat edelleen jatkuva haaste meriteollisuudessa. Tämä korostaa systemaattisempien ja datalähtöisempien lähestymistapojen tarvetta laadun parantamiseen.

Tämä tutkimus tutkii tuotteen laatuongelmia merimoottoriteollisuudessa globaalissa valmistusyrityksessä tehdyn tapaustutkimuksen avulla. Tutkimuksen tavoitteena oli tunnistaa merkittävimmät tuotteen laatuongelmien kategoriat, analysoida niiden perimmäiset syyt ja ehdottaa parannusehdotuksia niiden toistumisen estämiseksi. Tutkimuksessa sovellettiin Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) -menetelmää strukturoituna kehyksenä laadun parantamiseen. Tutkimuksessa käytettiin sekä määrällistä että laadullista dataa. Tuotelaatuongelmia koskevaa dataa analysoitiin kategorisoinnin ja Pareto-analyysin avulla merkittävimpien kategorioiden ja alakategorioiden tunnistamiseksi. Lisäksi valittuihin prioriteettialueisiin sovellettiin juurisyyanalyysitekniikoita, kuten kalanruotodiagrammia ja viisi kertaa miksi -menetelmää, jotta saatiin syvempi käsitys taustalla olevista syistä.

Tämän tutkimuksen tulokset osoittavat, että toistuvat tuotelaatuongelmat eivät johdu pelkästään teknisistä tekijöistä, vaan ne liittyvät vahvasti inhimillisiin ja organisatorisiin tekijöihin. Näitä tekijöitä ovat esimerkiksi epäselvät vastuunjaot, riittämättömät dokumentointikäytännöt, viestintäaukot ja toimintojen välisen yhteistyön haasteet. Nämä havainnot viittaavat siihen, että tehokas laadun parantaminen monimutkaisissa teollisuusympäristöissä edellyttää kvantitatiivisen laatu-tiedon integrointia kvalitatiivisiin johtamisnäkömyksiin. Tutkimus auttaa täyttämään kirjallisuudessa tunnistettuja aukkoja sekä tarjoamaan parannustoimenpiteitä sekä tapausyritykselle että koko merimoottoriteollisuudelle. Tutkimus tarjoaa myös jatkotutkimussuosituksia luoden mahdollisuuden laajentaa otantaa ja tutkimuksen merkittävyyttä.

AVAINSANAT: product quality, quality management, quality improvement, marine technology, manufacturing industry

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Abbreviations

AI = Artificial Intelligence

CCPAP = Case company supplier and part approval process

CI = Continuous improvement

FMEA = Failure mode and effects analysis

HFE = Human-Factors Engineering

LL = Lessons learned

PIP = Product improvement process

PQAP = Part quality assurance plan

QA = Quality assurance

QC = Quality control

R&D = Research and development

RCA = Root cause analysis

RO = Research objective

RQ = Research question

SM = Supplier Management

TQM = Total quality management

UE = Usability Engineering

1 Introduction

In today's world, product quality is critical to maintain (Lecomte, 2024). Quality is crucial to knowledge and to work for because without it, the organization can lose its' competitiveness. The key to an organization's success is quality, and more precisely, product quality (Calantone & Knight, 2000). Quality requirements are becoming stricter, and the pressure to deliver reliable and high-quality products throughout the product lifecycle is increasing. In complex engineering products, such as marine engines, quality failures can lead not only to high financial impact but also to operational disruptions, safety risks, and reputational damage for the organization. As well as the risen quality requirements, so has risen the complexity of products, systems, and processes (Reis et al., 2025). Rising complexity for products, processes, and systems is challenging product quality.

1.1 Background of the research

Product quality is especially important in the marine engine industry due to the complicated and changeable operating conditions (Xu et al., 2021). Marine engines must work accordingly with the changing conditions, as well as the long running hours. European engine manufacturers are obliged to ensure the highest quality possible (Laurent et al., 2022). Ensuring high quality happens through approved documentation certifications, makers and company audits. Even though these requirements and agreements exist, approximately 28 % of the quality inspections across the marine industry are missing or have insufficient documentation.

This research is conducted in a case company. The case company is a global leader in innovative technologies and lifecycle solutions for both energy and marine markets. Case company was founded in 1834 and started engine production in 1942. Case company manufactures a broad range of engines, not only diesel engines, but also with new fuels. The case company seeks opportunities to reduce the number of product quality issues by identifying and preventing root causes. Case company should be able to handle root cause analysis effectively to demonstrate that the defined actions have been

implemented and their implementation has been monitored. The case company for this research is seeking for a better organizational understanding of occurring quality issues. Also, it wants to strengthen the data-driven decision-making in quality improvement.

This research is conducted as a DMAIC (define, measure, analyze, improve and control) methodology. It gives this research a structured way to understand the case company's current situation. It also provides an approach to provide suitable improvement suggestions and action plans for them. Research includes both qualitative and quantitative data and their analyses.

Despite the extensive literature on product quality, quality management and continuous improvement methodologies such as DMAIC, the existing literature reveals several gaps. Empirical studies applying DMAIC largely focus on general manufacturing industries, with limited attention to product quality issues in the marine engine context. In addition, the literature provides insufficient guidance on defect categorization logic and its impact on prioritization and root cause identification. Furthermore, human and organizational factors are often underrepresented in quantitative quality studies, which tend to emphasize technical causes while overlooking qualitative insights and tool limitations. These gaps justify the need for context-specific, integrative research on product quality improvement in the marine engine industry. The gaps in the literature are discussed more in depth in Chapter 2.5.

The marine industry manufactures high complexity products with rising quality requirements as well as globally problematic guaranteeing of quality. This fact makes this research particularly relevant for both the case company and the whole marine industry. From the industry's point of view, improving the identification and prioritization of root causes in product quality issues can support the more effective prevention of issues. From the research's point of view, this research establishes ways to concur and prevent quality issues systematically and in a structured way.

1.2 Research objectives and questions

This chapter outlines the research questions and objectives that will guide this study. These elements define the focus of the research and provide a framework for addressing the identified problem of product quality issues in the marine industry. This research aims to provide a clear current state description of the product quality issues within the case company. By answering that question this research aims to find improvement/preventive suggestions. From this idea, two main questions for this research were identified. Research questions of this research are the following:

RQ1: What are the common causes of quality issues in marine industry engine products?

RQ2: What actions and practices can be adopted to minimize or prevent these engine product quality issues?

The aim of this study is to explore the root causes behind product quality issues within the case company. With conducting this study, the case company wants to receive, by pareto analysis, the three main categories that cause issues in product quality. The case company wants to prevent those issues from reoccurring and to also decrease the number of issues the company needs to handle on yearly basis. From this description of the situation, four research objectives have been set to this research. Those objectives support the research questions selected as well. The research objectives are the following:

RO1: To identify common factors contributing to challenges in product quality and to get an understanding of the quality issues by applying the six sigma DMAIC (define, measure, analyze, improve and control) methodology.

RO2: To analyze root causes (given data from the case company) leading to quality issues and to categorize them into relevant categories to find the main category.

RO3: To subcategorize the main category and to apply Pareto analysis to rank the most significant subcategories in leading to quality issues. Also, to analyze three of those most significant categories by performing a root cause analysis (5 whys, fishbone diagram).

RO4: To recommend actions and preventive measures that can be adopted to reduce or eliminate product quality issues.

The research questions focus on identifying the common causes of product quality issues in the marine industry and exploring actions and practices to minimize or prevent these issues. These questions are supported by objectives that aim to provide a structured approach through the application of Six Sigma DMAIC methodology, root cause analysis and Pareto prioritization. By addressing these objectives, the study seeks to deliver actionable insights for the case company and for the marine industry, enabling it to reduce recurring quality problems and improve overall product reliability. Ultimately, this framework ensures that the research remains aligned with its purpose, which is to understand the current state of quality challenges in the marine industry and propose preventive measures that contribute to long-term improvement.

1.3 Structure of the thesis

This thesis is structured as a coherent and logical whole, in which each chapter builds meaning from the previous one and provides input for the next chapter. Thesis follows a clear progression that allows the reader to understand how the research develops from problem identification to analysis, improvement suggestions and conclusions of the research.

The thesis begins with Abstract, Table of contents and Abbreviations. Following the Chapter 1 provides the basis for the entire study. It introduces the importance of product quality in the industrial and marine engine context and outlines the background and motivation for the research. It defines the research objectives and questions and represents the case company. Chapter 2 builds on this by reviewing relevant literature on product

quality, quality issues, continuous improvement, DMAIC, and quality tools. It provides a theoretical framework and identifies research gaps that justify the research.

Chapter 3 describes the research design, case study approach, data collection, and the application of the DMAIC methodology. It enables the systematic empirical research presented in Chapter 4. Chapter 4 describes the DMAIC phases in detail and what has been done. Chapter 5 discusses empirical findings in relation to existing literature and reflects on the research questions and objectives. Lastly, Chapter 6 concludes the research and its findings. It also provides an evaluation of the research limitations and future research implications.

2 Literature review

This chapter examines the key theories and concepts related to the case company's problem. In this chapter, the most important concepts are explained and described to create a foundation for the empirical phase. The literature review focuses on industrial manufacturing industries to ensure that the information processed is in a context appropriate to this research. Industrial manufacturing industries include marine and automotive manufacturing, which are both relevant fields for this research.

This literature review introduced the reader to the concept of quality. Specifically, it will discuss quality in an industrial context to keep it linked with the case study introduced later on. After giving a solid understanding about the concept of quality, the literature review brings up quality issues and product defects. For this case study, introducing the common quality defects is crucial, because it determines a solid background for the empirical study, which will focus on improving the current situation of defect detection, categorization, and analysis. To be able to compare the empirical study results and findings, the commonly used strategies, approaches, and tools for quality management and quality defects are also presented. With this literature review, this study is able to analyze the current situation of quality defects in the industrial context and compare that to the case study. This is strongly connected to the research question one.

2.1 Product Quality in an Industrial Context

The concept of quality in an industrial context is multifaceted and varies under different circumstances (Naidu et al., 2006). Naidu et al (2006) discuss the fact that quality does not only refer to the characteristics of a manufactured product. It also refers to the quality of processes, including men, materials, machines and even management practices. Calantone and Knigh (2000) discuss that quality includes all the activities that add value to the organization.

Quality in an industrial context can be divided into four types of quality: product quality, process quality, service quality, and environmental quality (Lecomte, 2024). Each quality type can be seen as a part of customer satisfaction and an organization's competitiveness. Balancing all these types, organizations can reduce risks and improve performance such as production control.

When referring to product quality, it is commonly defined as the degree to which a product fulfils customer requirements (Lecomte, 2024). According to Naidu et al. (2006), this definition is not absolute. Rather, product quality is judged by comparing the product against established standards. Calantone and Knight (2000) discuss product quality from the same aspect, referring product quality to being dependent on product characteristics, marketing, delivery and value received.

Product quality determination typically involves evaluating characteristics such as design, product size and material, chemical composition, mechanical functioning, and workmanship (Naidu et al., 2006). Naidu et al. (2006) and Bhat (2009) divide product quality into three characteristics:

1. Quality of design
2. Quality of requirements
3. Quality of performance

Hence of this, product quality begins with product design in accordance with customer specifications and extends to the selection of appropriate materials, manufacturing processes, tooling, and inspection to ensure conformance to requirements.

Quality is an integral part of the entire industrial process (Figure 1). Suppliers, production, assembly, design, and customers all influence quality and at the same time are affected by the product's quality. In the industrial context, product quality has been developing throughout the years. Previously, product quality was more seen and controlled as the product's technical requirements, such as the number of defects and the equipment reliability. Nowadays, industrial manufacturing companies increasingly focus on product

quality in product design, human resource management, and supplier relations. This has made the change that quality is not just quality control departments' work, but it is spread out to the assembly, product design, and to the suppliers (Bhat, 2009, p. 38-40).

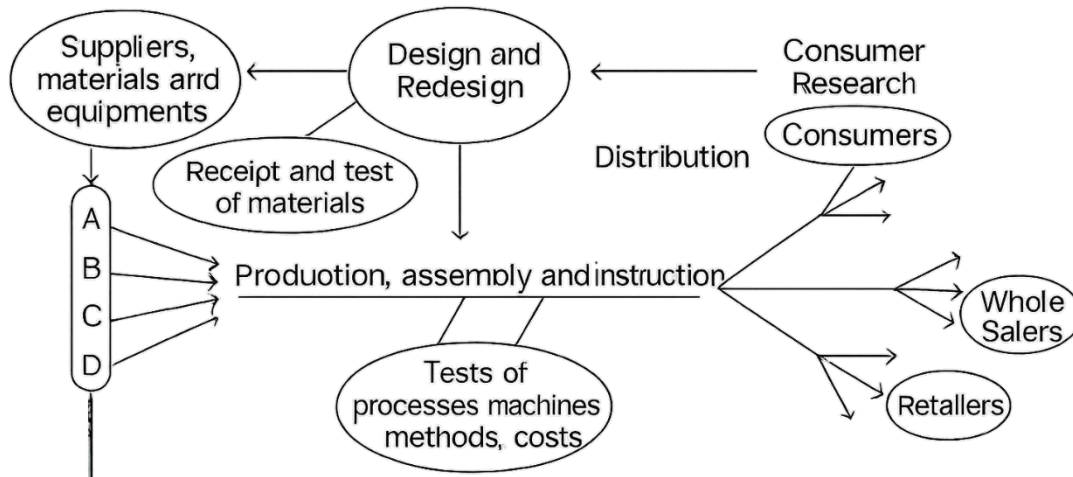


Figure 1. Quality in Production System (Bhat, s. 17, 2009).

Quality management is an umbrella concept for quality control and assurance (Figure 2)(American Society for Quality, 2026a). Quality management can be divided into quality control (QC) and quality assurance (QA). QA (quality assurance) and QC (quality control) are somewhat related to each other, but they are always defined differently. As can also be seen in Figure 2, QA is typically covering everything in the organization's quality system, whereas QC is a part of these QA ways.



Figure 2. Overview of the management of Quality (American Society for Quality, 2026a).

More in detail, QA can be defined as the organization's activities that it performs to provide quality products (K. S. Bhat, 2009). QA is two-faced (American Society for Quality, 2026a): it affects management internally and customers externally. QA is commonly connected to the quality standard family ISO 9000 (ISO, 2026). It gives organizations guidance for their QA and requirements for quality management systems.

QC includes all the activities and factors that an organization is doing to fulfil its quality objectives and standards (K. S. Bhat, 2009; Naidu et al., 2006). This involves observing performance, comparing it with standards, and taking corrective action when deviations occur. QC is an industrial management technique aimed at producing goods with acceptable quality. This is often achieved through adherence to international standards and the principles of Total Quality Management (TQM), which emphasizes building quality into products (Figure 2). Since product quality starts from the supplier and continues all the way to the customer (Figure 1), so does QC. Production system, raw materials,

parts, and supplies must be controlled and accepted by quality before the organization can use them. QC is doing this. It determines the quality standards.

For a successful product quality management, organizations need to adapt the quality tools and techniques used in each sector and process (Lecomte, 2024). The quality key performance indicators (KPIs) and the analysis of them are both essential elements in successful QC. Key performance indicators can measure how an organization performs in terms of quality objectives and standards (Twin, 2025). KPIs can be finance-, customer- or process-focused. With KPIs, organizations can compare their performance against benchmarks, competitors, and their overall business performance over time.

All in all, product quality has an impact on efficiency and profitability (Lecomte, 2024). By having the right quality approach and management, an organization can increase operational efficiency, improve customer satisfaction, and increase company profitability. It is a vital determinant of organizational success. In the long term, the quality of a firm's offerings relative to competitors significantly influences business performance (Calantone & Knight, 2000). High-quality products enhance reputation, enable higher profits, expand market share, and support business growth. Thus, quality is not merely a technical requirement but a strategic concept that managers and employees can actively control (Calantone & Knight, 2000).

2.2 Product Quality Issues in an Industrial Context

Product quality issues in the industrial context often proceed from defects that escape detection during production (Sadikin, 2023). When we are talking about manufacturing organizations and industries, defective products are part of it (Sreedharan V. et al., 2018). Approximately one engine damage claim costs 550 000 euros, which clarifies the importance of identifying and understanding quality issues (Stålberg, 2024). There isn't a situation where an organization wouldn't phase defects in their products even though there is proper quality management, product design, and manufacturing process. Safety in manufactured products represents a major concern in the industrial context (K. S. Bhat,

2009). All parties involved in the design, manufacturing, sales, and service of a defective product may be held liable for damages. Attention to design quality significantly reduces the likelihood of liability claims.

Product defects often stem from underlying process failures within the production system (Sadikin, 2023). Also, a previous study about ergonomics influence in improving product quality from Erdinc and Vayvay (2008), shows that human factors such as human work performance and errors are the main reasons for product quality defects in the industrial manufacturing field. Also, Kolus et al. (2018) studied that approximately 91 % of product quality issues were related to human factors such as work procedures, instructions, and training policies. As this is said, it can be stated that product quality relies on both technical and human factors (Kolus et al., 2018). In detail, product defects can result from poor raw material quality, inadequate quality control mechanisms, or systemic weaknesses in manufacturing processes (OpsNinja, Inc, 2025; Sadikin, 2023). Furthermore, earlier literature underscores how communication gaps inside industrial organizations can lead to quality issues (Bjarnason et al., 2011).

Implementing RCA and proactive quality management strategies is critical for mitigating these risks and maintaining competitiveness (*Identifying Defects*, 2025). Without root cause analysis and effective addressing of root causes, these defects can't be prevented from reoccurring (Sadikin, 2023). Effective root cause analysis ensures sustainable quality improvement. Failure to address defects within manufacturing facilities can lead to major consequences such as lost revenue, reduced productivity, wasted materials, and reputational damage (*Identifying Defects*, 2025). Also, the issues regarding to improving and preventing root causes of defects may stem from human causes (Erdinc & Vayvay, 2008.; Kolus et al., 2018) or organizational causes (*Identifying Defects*, 2025; Sadikin, 2023).

For the categorization of defects, the base idea comes from categorizing defects according to activities and development phases that are associated with the defect and its

repairment (Chi et al., 2020). Product defects are categorized into three main types, of which the first two categories are commonly (Hora et al., 2011; OpsNinja, Inc, 2025):

- Design defects: inherent flaws in the product's blueprint, making it unsafe or unsuitable for intended use.
- Manufacturing defects: deviations during production caused by assembly errors or substandard materials.

The third category is identified differently based on the reference. For example, Hora et al. (2011) define the third category as mislabeling of a product. On the other hand, the Understanding Defects in Products (2025) article has determined the third category as marketing. Both determinations are leaning on the same explanation: product instructions, product presentation, overall instructions, and advertising. The case company uses manufacturing/internal operations, supplier, and design categories, and no subcategories. Subcategorizing is also common to do for defects, because it gives the possibility to go deeper into the analysis of the main defects (Chi et al., 2020).

There aren't specifications for subcategorization inside these main categories. It is more done based on the context and the need for it. For example, Chi et al. (2020) discussed the design category's subcategories in their article. They mentioned:

1. Component design flaws
2. Material selection failure
3. Software failure

The case company doesn't yet have specifications for subcategorization.

Bhat emphasizes (2009) that as well as there are design and manufacturing related defects, suppliers contribute to the detected and determined defects also. If the quality of purchased parts and services isn't as high as needed, the quality of the manufactured products will also not be as high as needed. In today's research, supplier quality isn't taken into account as its own defect category, like the manufacturing and design categories were.

Product quality issues can significantly impact customer satisfaction, operational efficiency, and an organization's reputation (Sadikin, 2023). Product defects affect both operational performance as well as customer relationships (Fasciane, 2018). Both Fasciane (2018) and Sadikin (2023) discuss the most critical concerns and consequences of product quality issues. Fasciane (2018) states that the most immediate consequence of defective products is the increase in external failure costs. These costs arise from wasted raw materials, labor, and additional expenses associated with repairing or replacing rejected products. As Fasciane (2018) notes, the higher the reject rate, the greater the financial burden on the manufacturer.

One of the most critical concerns about poor quality products is the organization's reputational damage (Sadikin, 2023). Customer trust and brand image are both closely linked to product quality. Defective products can lead to customer dissatisfaction, which often results in customers seeking alternatives from competitors who offer better quality standards. This erosion of trust can have long-term consequences for market positioning. Also, product defects negatively impact productivity. When products require reprocessing or replacement, production flow is disrupted, lead times are extended, and delivery schedules are compromised. Such disruptions reduce overall efficiency and can create bottlenecks in the manufacturing process.

Traditional QA methods rely heavily on manual inspection, which makes defects harder to detect and prevent (OpsNinja, Inc, 2025). Manual inspection processes are slow, labor-intensive, and prone to subjectivity, which leads to inconsistent decisions and undetected imperfections. For example, inspectors may overlook minor defects in electronic components, which can later cause systemic failures. Outdated and manual processes also limit visibility across operations, making early detection of defects difficult. The lack of efficient quality control in industrial manufacturing organizations has a significant financial impact. For example, in 2023, organizations in the United States incurred this lack of efficiency has significant financial implications; in 2023, businesses in the United

States incurred approximately 47 million euro fines (55,3 million dollars) due to defective products and suffered additional losses from recalls (Cayabyab, 2025).

Each defect type poses unique risks, necessitating robust quality control and regulatory compliance (OpsNinja, Inc, 2025). Defect reduction is therefore a critical aspect of quality improvement in industrial manufacturing organizations (Sadikin, 2023). Defect reduction can minimize the mentioned impacts that product quality issues have. Consequently, documentation of quality assurance becomes essential, including records of test procedures, monitoring of critical product characteristics, feedback on inspection results, and corrective actions taken (K. S. Bhat, 2009).

2.2.1 Design defect

Design is one of the commonly used categories in defect categorization (Chi et al., 2020; Hora et al., 2011; OpsNinja, Inc, 2025). Product design determines the technical specifications and requirements for the product itself and for its production processes (Bhat, 2009, p. 39-40). With the correct product design, it can be ensured that the product will meet customer needs, fill the marketplace and result in good quality. If the product's design is under designed, overdesigned or poorly designed, the product won't be able to make the requirements and specifications necessary. Also, the costs of the product will rise, with an unsuitable design for the purpose.

There are different types of design defects regarding products, depending on the product context and industry. In the industrial manufacturing context, product design defects can be for example flaws in material selection, component design and software (Chi et al., 2020). In the product design, it is needed to take into account the environment, where the product is going to be used and know how the components, materials and software work in different operation conditions. Design defects often stem from inadequate planning, insufficient testing and failures regarding the comprehensive considering of user's needs (OpsNinja, Inc, 2025).

To this end, design defects are embedded in the conceptual stage and affect every unit produced from the flawed design. Such defects typically result in products failing to perform as intended or not meeting established safety standards (Nguyen, 2025). Nguyen (2025) states three characteristics that can be used to identify design defects:

- The product does not achieve its intended functionality.
- Safety standards are compromised, creating potential hazards.
- The defect is systemic, appearing in all units manufactured from the design.

As an example of a design defect, Nguyen (2025) describes a phone that overheats because of inadequate cooling mechanisms. This example describes the importance and also the criticality of product design perfectly. If the product design isn't perfect, some things won't work and it can lead to defects. An example from out of the industrial manufacturing context is for instance, toys that break easily and pose choking hazards, which exemplify poor design practices (OpsNinja, Inc, 2025). These issues highlight the importance of integrating Human-Factors Engineering (HFE) and Usability Engineering (UE) principles into the design process. By focusing on user experience and answering critical questions, such as who the users are, what the intended uses are, and the environments in which products will operate, manufacturers can mitigate risks before they escalate into serious hazards (OpsNinja, Inc, 2025).

In order to prevent design defects, a structured approach is needed (Nguyen, 2025; OpsNinja, Inc, 2025). Design defect prevention approach could include for example:

- Conducting thorough design reviews and risk assessments.
- Implementing rigorous testing and prototyping before mass production.
- Applying HFE and UE principles to anticipate user needs and environmental conditions.

These strategies help organizations reduce liability risks, enhance product safety, and maintain customer trust.

One commonly used tool for preventing design defects is failure mode and effects analysis (FMEA). FMEA is used as a tool for conducting design reviews and risk assessments. FMEA is an analysis tool to identify and prioritize design failures (American Society for Quality, 2026b). In FMEA, the way something might fail, as well as the consequences of the failure, are analyzed. The failures are prioritized by analyzing the defects' consequences, frequency, and defect detection. FMEA is also used to document the current situation and actions regarding failure situations, to be able to continuously improve the products. Parsana and Patel (2014) did a case study about the use of FMEA tools to enhance quality in the manufacturing industry. As a conclusion, Parsana and Patel (2014) stated that using FMEA, can improve the product quality of an industrial manufacturing company. FMEA decreases the amount of product defects and for that saves the organization money and time (Parsana & Patel, 2014).

As a conclusion, we can say that product design processes significantly influence both market success and operational efficiency. A well-executed design not only meets customer requirements but also ensures compatibility with production processes. Poor product design can undermine market potential regardless of manufacturing quality, as design defines the product's functional specifications and fitness for use (K. S. Bhat, 2009). Furthermore, design decisions affect manufacturing efficiency, flexibility, and cost-effectiveness, making design a critical determinant of strategic organizational goals (K. S. Bhat, 2009). Core design processes, those that directly add value to products and services, require a lot of attention, which primarily serve internal operational needs. Aligning design with production and delivery processes ensures that products conform to specifications and can be produced economically and efficiently (K. S. Bhat, 2009).

2.2.2 Manufacturing defect

As well as design, manufacturing has to ensure good quality in the production process, assembly, and also in the final product (Bhat, 2009, p. 39-40). It isn't always possible to ensure good quality because manufacturing defects occur. A manufacturing defect refers to a flaw or imperfection that occurs or happens during the production or assembly

process (Cayabyab, 2025; OpsNinja, Inc, 2025). Manufacturing defects causes the product to deviate from its intended design (Cayabyab, 2025).

Manufacturing defects are typically unintentional and often result from errors (Cayabyab, 2025). These errors and flaws leading to manufacturing and assembly defects can be for example, faulty machinery or such as the use of substandard materials or inadequate quality control measures. Consequently, the product may fail to function as expected, pose safety risks or fall short of the standards promised by the manufacturer. Manufacturing defects differ from design defects in that they arise during production rather than at the conceptual stage (OpsNinja, Inc, 2025). While the design may be perfectly done, execution errors compromise the product's integrity.

The article "Understanding Defects in Products: Classification, Causes, and Impact (OpsNinja, 2025), concludes the factors contributing to manufacturing defects. Manufacturing defects can be divided into the following subcategories:

- Human error: the mistakes during assembly or inspection.
- Machinery malfunctions: the equipment failures that affect production accuracy.
- Substandard material: the poor-quality input that compromises product performance.

Manufacturing defects can have severe consequences for organizations, including lost revenue, wasted materials, and reputational damage (Cayabyab, 2025). Defective products may lead to malfunctions, accidents or injuries, exposing manufacturers to legal liabilities and eroding customer trust. Furthermore, unresolved defects disrupt production flow, create bottlenecks and increase operational costs. Effective defect management for manufacturing defects is essential for maintaining product quality and safety standards. Key strategies for manufacturing defect management includes (Cayabyab, 2025; *Identifying Defects*, 2025; OpsNinja, Inc, 2025):

- Implementing Root Cause Analysis (RCA) to identify and eliminate underlying issues rather than applying temporary fixes.

- Adopting advanced technologies such as AI-powered flaw detection systems, which provide instant and accurate recognition of subtle imperfections, thereby improving efficiency and reducing reliance on subjective human judgment.
- Strengthening quality control protocols and ensuring rigorous monitoring throughout the production process.

These measures help organizations minimize defects, reduce costs, and maintain competitiveness in increasingly demanding markets.

2.2.3 Marketing/mislabeling defect

The third of the most common category for defect categorization was determined as marketing or mislabeling defects (Hora et al., 2011; OpsNinja, Inc, 2025). The determination of this third category was done by using both perspectives, marketing and mislabeling. Marketing or mislabeling defects are related to the product information, warnings, instructions, and specifications. This means that if these listed things are in some way incorrect or insufficient, it can lead to misuse of the product, and the end result is a marketing or mislabeling defect. As part of product liability, the manufacturing company is required to provide these previously mentioned labels for each product produced (Ross, 2020).

Stålberg (2024) has conducted an engine damage report with several case studies about common engine issues. In the report, Stålberg (2024) emphasizes that many of the defects stemmed from the poor following of the manufacturer's instructions for maintenance and operation. With this example, it is intended to illustrate what is not categorized as marketing or mislabeling defect. For example, if the customer doesn't follow the instructions or warnings issued by the manufacturer, the resulting defects do not belong to the marketing or mislabeling category.

To prevent these defects, Ross (2020) states that: "Say what you mean and mean what you say". Manufacturing companies need to know for sure how the product performs and then to be able to promise that. Without certainty that the product will perform in

a certain way, the company can not promise that. Using this as a guideline when labeling and marketing products can lead to improvement in customer satisfaction. Also, it can lower the risk that the manufacturing company is facing when selling products.

2.3 Approaches to addressing Quality issues

In this chapter, the approaches and concepts for addressing quality issues in industrial manufacturing organizations are introduced. The manufacturing industry is evolving, and for that the requirements and needs for quality has been growing (Ghelani, 2023). With the help of different quality approaches, organizations can enhance their quality in processes as well as in products.

Before introducing the different approaches, a roof concept, continuous improvement (CI), is introduced. CI represents a proactive philosophy aimed at enhancing organizational processes before problems escalate (Lloyd, 2025; Team, 2025). CI is a mindset, not a single method. It has been studied that organizations that recognize and implement CI, can reduce their operational costs and improve their productivity (Team, 2025). Rather than relying on reactive measures, CI encourages systematic problem-solving at every level of an organization. By embedding CI into daily operations, organizations can strengthen their process efficiency, support operational excellence and maintain competitiveness in dynamic markets. Without CI, organizations might have difficulties in achieving effective and efficient processes (Gutiérrez et al., 2016). The inclusion of management, as well as the whole organization, is a crucial step for achieving well-performing CI.

At its core, CI is not a one-time initiative but an ongoing commitment to identifying opportunities for refinement and implementing incremental changes (Lloyd, 2025). Key perspectives for describing the main focus of CI are (Brunet & New, 2025):

- Continuous: used to describe the nature of the approach and also its meaning in the continuous journey of improving.

- Incremental: used to describe the nature of the approach and detect the difference between it and organizations managements big decisions.
- Participative: Used to describe how it is implemented inside organizations and how it affects the workforce.

Even though CI provides a strong guiding philosophy, it commonly has barriers in implementation (Singh & Singh, 2015). Previous studies discuss these barriers preventing a successful CI implementation. For example, barriers can be such as poor planning and training (Rahim & Whalen, 1994), lack of commitment from management (Ngai & Cheng, 1997), and lastly, politics and wanting a quick fix (Salegna & Fazel, 2000). To overcome the barriers, CI requires concrete methods and structured approaches to overcome the barriers of implementation, such as Six Sigma and Kaizen. CI approaches and methods serve as a cornerstone for operational excellence (Lloyd, 2025). They enable organizations to respond effectively to evolving customer expectations, regulatory requirements, and competitive pressures, ensuring sustainable growth and superior outcomes.

2.3.1 Kaizen

Kaizen is a people-driven approach of continuous improvement. Kaizen is derived from the Japanese words Kai (change) and Zen (good). It emphasizes small incremental changes rather than large-scale transformations. It is aiming to enhance processes, reduce waste and improve efficiency over time (Furterer, 2021, p. 55-57). Kaizen is widely recognized as a cultural approach that requires organizational commitment and employee involvement at all levels. Kaizen methodology has core principles, which ensure that the improvements are not just implemented but also maintained (Munro et al., 2022, p. 960-961). The core principles are:

1. CI through incremental changes
2. Employee participation and empowerment in problem solving
3. Standardization of improved processes to sustain gains

Successful Kaizen implementation requires a cultural shift toward openness, collaboration, and accountability. Organizations must foster an environment where employees feel empowered to suggest improvements and participate actively in change initiatives (Furterer, 2021, p. 55-57). Kaizen aligns closely with the Plan-Do-Check-Act (PDCA) cycle. The PDCA cycle ensures that changes are planned, tested, and standardized before being fully implemented, reinforcing Kaizen's iterative nature (Munro et al., 2022, p. 972).

2.3.2 DMAIC

The Define, measure, analyze, improve and control (DMAIC) methodology is used when problems become too big to be addressed with the continuous improvements Kaizen approach (Pereira, 2024, p. 101; Furterer, 2021, p. 69-73). DMAIC provides a structured problem-solving logic that is more suitable for complex problems where finding the root causes is essential. DMAIC methodology implements continuous improvement by addressing the analytical and planning-related barriers.

The DMAIC approach is a main part of the Six Sigma methodology, designed to reduce variation, improve quality, and enhance process efficiency (Pereira, 2024, p. 101; Furterer, 2021, p. 69-73). DMAIC comes from the words Define, Measure, Analyze, Improve and Control. It represents the five important phases that guide problem-solving and CI efforts. DMAIC is not only a problem-solving tool but also a driver of CI. Organizations adopting DMAIC benefit from reduced defects, improved customer satisfaction, and long-term operational excellence (Pereira, 2024, p. 101). Its structured nature makes it adaptable across industries and processes.

Six Sigma emerged as a quality management philosophy in the 1980s at Motorola and gained widespread adoption in the 1990s through companies like General Electric (Furterer, 2021, p. 69). DMAIC provides a structured roadmap for addressing defects and inefficiencies by focusing on data-driven decision-making and systematic analysis. It is widely recognized as the most common Six Sigma methodology (Munro et al., 2022, p. 329). Each phase of DMAIC serves a distinct purpose in the improvement cycle:

1. **Define:** The first step involves clearly articulating the problem, project goals, and customer requirements. Projects team identifies quality characteristics and establish the scope of improvement (Munro et al., 2022, p. 423).
2. **Measure:** In this phase, data collection is prioritized to understand the current situation and the current process performance. Tools such as process maps, Pareto charts, and statistical analysis help quantify variation and establish baselines (Furterer, 2021, p. 73).
3. **Analyze:** The analysis phase focuses on identifying root causes of defects or inefficiencies. Techniques like hypothesis testing and regression analysis are commonly applied to validate assumptions and uncover relationships (Munro et al., 2022, p. 424).
4. **Improve:** Solutions are developed and implemented to address the root causes identified. This may involve process redesign, error-proofing, or introducing new technologies to enhance performance (Furterer, 2021, p. 73).
5. **Control:** Finally, measures are put in place to sustain improvements over time. Control plans, monitoring systems, and documentation ensure that gains are maintained and prevent regression (Munro et al., 2022, p. 425).

DMAIC methodology is widely used in the manufacturing industry (Sadikin, 2023). DMAIC's occupancy rate was 23 % and Six Sigma's 17 % in research that studied the methods used in the reduction of defective products. The DMAIC approach has proven its capability to reduce an organization's amount of defective products and the processing costs of poor quality products (Daniyan et al., 2022; Girmanová et al., 2017; Imansuri et al., 2024; Sumasto et al., 2023). DMAIC methodology is supporting more effective, stable, and cost-effective processes (S. Bhat et al., 2021). Also, DMAIC methodology has been studied to affect the service quality (Gutiérrez et al., 2016).

DMAIC provides a consistent and comprehensive methodology for implementing the continuous improvement philosophy into an organization (S. Bhat et al., 2021). Although, DMAIC is a structured methodology, it can provide successful results, even if not

followed perfectly (Gutiérrez et al., 2016). However, DMAIC provides variability in tools for it to be suitable for many different situations, which can be seen as a huge benefit of it (Maryani & Purba, 2021).

2.4 Quality tools for product quality improvement

There are various tools and techniques for improving product quality. In this chapter, the focus is on the quality tools that are commonly combined with DMAIC methodology. The tools presented are later used in the application of DMAIC in this research.

Commonly used quality tools in DMAIC methodology are, for example, the Pareto chart and the different techniques of root cause analysis (Atmaca & Girenes, 2011; Girmanová et al., 2017). With the help of the right tools, organizations can achieve higher product quality. Quality tools help organizations implement CI.

2.4.1 Root cause analysis

Root cause analysis (RCA) is a significant quality tool used in manufacturing industries (Pietsch et al., 2024). With the rising quality requirements and the organization's need to pursue for better and better product quality, product issues and defects need to be addressed and prevented. Product quality issues often proceed from underlying factors within organizational processes, such as assembly, manufacturing, and design (Jenkins, 2025). Identifying these root causes is essential for implementing effective corrective and preventive actions (ABS Consulting et al., 2008; Jenkins, 2025). RCA is one of the many activities that organizations should undertake to minimize the probability and impact of failures. RCA's goal is to be able to answer the questions: Why an issue have occurred, and how can the issue be prevented (Groot, 2021). Also, it helps organizations determine what factors are driving the product quality and what consumes it. RCA is integral to continuous improvement frameworks like Six Sigma and Lean Manufacturing (Jenkins, 2025). When embedded as a core competency, RCA accelerates problem resolution and fosters a culture of accountability and operational excellence.

RCA is usually initiated in product issues when there are triggers like product defects or failures, machinery breakdowns, safety incidents or recurring problems. To start the RCA process, there are several steps (Groot, 2021; Jenkins, 2025):

1. Define the problem
2. Collect Data
3. Analyze data
4. Identify root causes
5. Identify improvement and preventive actions

RCA is a reactive analysis (ABS Consulting et al., 2008, p. 35-36). In a perfect world where the proactive analysis and management systems implementation have been made perfectly, reactive analysis isn't needed because there wouldn't be incidents to analyze. That is only possible in the imaginary world, not in the real world. So often, reactive analysis, such as RCA, is needed. When implemented, the results from the RCA are going to change the proactive analysis and the management systems. Implementing RCA into the investigation of product quality issues has significant benefits, such as (Jenkins, 2025): reducing costs and improving productivity, processes, and product quality. For a successful implementation of RCA, it is important to have a collaborative system and atmosphere between different departments of the company (Groot, 2021). Also, within the organization, it is important to foster an accepting and non-accusatory culture.

In the literature of RCA, a systematic approach to RCA is considered important (Groot, 2021). Also, the need to understand complex situations where product issues occur is highlighted. These are necessary to be able to find the underlying root cause as well as the actions to prevent the issue from recurring. RCA tools are commonly based on linear models, meaning that the tools might simplify realities too much to just find the root cause (Groot, 2021). This can lead to missing the real root causes and only focusing on simpler improvements and preventive actions. These linear RCA tools guide the user to a single root cause, which can also lead to missing the real root causes. Without looking at different directions and from different perspectives, it is hard to find all the interacting

causes within a system or a process. Commonly in organizations, RCA lacks sufficient depth.

For RCA to be effective, identified causes must be actionable (Sarkar et al., 2013). Actionable causes exhibit three properties:

- They are under the control of the relevant team or management.
- They can be explained with numerical values.
- They are expressed negatively rather than positively, making them easier to validate and address.

In RCA several recurring traps and categories have been identified that contribute to product quality problems (ABS Consulting et al., 2008, pp. 86–87; Jenkins, 2025). The first common trap is equipment issues where the company believes that the problems are affected by the lifetime of parts or when they think that the parts were just not in the best shape. In this case, the company won't find the real root cause, they only find the equipment issue. The second common trap is human performance issues. In this company only looks at the employees involved in the problem and blames them, not looking at the root cause. For example, not asking "Are we providing enough training and are they efficient?", only blaming the employees but not looking for the root cause, why the employee wasn't able to concur the problem. The third trap is external event issues. In this trap the company sees the problems as a natural event that they don't have control on. Even though this might be true in some cases, it also is in the hand of the company to for example address nature and other external events to minimize their impact if they occur.

Despite its benefits, RCA can be time-consuming and resource intensive. Defining root causes often requires months of data collection, analysis and validation and may involve multidisciplinary teams (Ito et al., 2022). Limited time and expertise frequently result in incomplete investigations or inaccurate conclusions, allowing problems to recur (Ito et al., 2022). Itself the root cause analysis stage is rarely the most time-consuming or

difficult, if you have done the preparation stages well (Andersen & Fagerhaug, 2006, p. 62-69). There are four most used root cause analysis tools:

- Cause and effect chart or Fishbone diagram
- Matrix diagram
- Five whys
- Fault tree analysis.

The most meaningful root cause analysis tools for this research are the cause and effect diagram and the five whys. These are commonly used in the industrial manufacturing field and are known to suit its needs.

The first one, the cause and effect diagram or fishbone diagram, is also known as Ishikawa diagram (Andersen & Fagerhaug, 2006, p. 62-69). It was developed by Kaoru Ishikawa in the 1960s (Sahoo, 2021, p. 47). It is described as the easiest tool in the root cause analysis tool family. It analyzes the relationships between a problem and its causes as a chart (Andersen & Fagerhaug, 2006, p. 62-69). The main purpose of it is to understand what causes of the problem. It can be used to two different purposes: to cluster and generate problem causes and to evaluate and determine which of the causes are most likely root causes of the problem. The case company is also familiar with the fishbone diagram.

The second tool used, the matrix diagram, allows the user to find study number of possible causes (Andersen & Fagerhaug, 2006, p. 62-69). It also determines which of the causes affects the most to the problem. The main purpose of this tool is to analyze the relationships between causes and problems. Matrix diagrams strength is the fact that it has an ability to graphically picture multiple connections. Matrix diagram can be used for defining the overall impact of all possible causes and to determine which of the causes is the root cause

The third tool used is called five whys. It is also usually referred as the why-why chart and root cause analysis (Andersen & Fagerhaug, 2006, p. 62-69). Five whys tools main

purpose is to ask "why?", constantly. When the cause is identified, the process starts by asking "why?" five times to achieve the root cause. It can be used to categorize if the cause is a symptom, a lower-level cause or a root cause and to dig deeper into the search of root causes. The five whys tool is commonly used in the manufacturing industry. The case company is also familiar with it.

Fault tree analysis is the fourth tool used in root cause analysis. It is a diagram that portrays all the possible causes in it (Andersen & Fagerhaug, 2006, p. 62-69). It identifies links between the causes and builds its result with the five whys analysis. It is used for getting a clear overview of the causes and to see the links between the causes.

2.4.2 Pareto analysis

The Pareto principle was developed by an Italian economist, who studied mathematical relationships between vital few and trivial many (Gordon, 2002; Naidu et al., 2006). Pareto charts apply the 80/20 principle, which states that roughly 80 % of the problems are caused by 20 % of the causes. This tool helps to prioritize improvement efforts by focusing on the most significant issues (Furterer, 2021, p. 73-83). The Pareto analysis eases improvement of quality by enabling the organization to prioritize the most critical issues to achieve the needed and wanted goals (Alkiayat, 2021). Pareto principle comes from the concept that the effects of different factors that lead to issues are not equal.

As said, its purpose is to identify the most vital factors that contribute the most to a problem. To make a Pareto chart, data needs to be collected and categorized by the type of defect or issue. Then the categories are plotted in descending order of frequency or impact, with a cumulative percentage line added to highlight the most critical contributors (Naidu et al., 2006, p. 91). The benefits of using Pareto charts are that it provides a clear visual representation of priorities and it maximizes the resource efficiency by addressing the most impactful problems first. Pareto is commonly used in production and maintenance to analyze non-conformance, machine break downs and utilization. Pareto principle is commonly used in quality improvement projects to identify and scope the

problem that is addressed (Alkiayat, 2021). It can also be helpful to use in the evaluation of the implementation of improvement actions. Upper management commonly wants an outcome to happen and that can be done by identifying the most significant factors contributing to it (Alkiayat, 2021). Pareto analysis enables quality control and prioritization for organizations (Gordon, 2002).

Even though Pareto analysis is a great method, it has its weaknesses. One of the main weaknesses is that Pareto analysis only concentrates on the past (ABS Consulting et al., 2008, p. 124-125). It is based on historical data and only relying on the past, isn't always the most accurate way. For example, it doesn't take into account those problems or incidents that haven't yet happened or they only occur rarely. Those problems and incidents can be as significant as the ones that occur more often. Also, new changes in the operating practices can mess with the decisions that are based on the analysis. When a new practice is taken into use, there needs to be a relatively long time before analyzing it to make sure that there is enough data to analyze. In Pareto analysis the categorizing is made based on the judgment of people doing it. This leads to variability in the time of the analysis and to the different levels of result presented from the analysis. Because of Pareto analysis only depending on the data, it is also crucial to have reliable and relevant data available to produce a good quality analysis.

2.5 Gaps in existing literature

The existing literature provides a broad theoretical foundation on product quality, quality management, continuous improvement and the use of quality methodologies and tools, such as DMAIC, Kaizen, root cause analysis and Pareto analysis. However, despite this comprehensive theoretical coverage, gaps in existing literature can be identified to justify the need for present research. In this chapter, the gaps are introduced and explained.

The first gap identified is regarding the fact that most quality and DMAIC studies found in the literature were from manufacturing industries, such as automotive and electronics. There weren't specific studies about product quality in marine engines. The empirical

research was limited to this context about product quality issues, recurring defects in marine engines, and using the DMAIC methodology to improve.

The second gap identified was the lack of focus on defect categorization logic. Categorization is recognized as an important step in quality analysis, but the existing literature provides limited guidance and research on how defect categories and subcategories should be defined, justified, and applied in practice. Subcategorization is often mentioned as context dependent, but the limitations of the chosen subcategories are rarely discussed. How the chosen categorization and subcategorization affect the outcome, prioritization (Pareto analysis), and root cause identification is not discussed in the literature. Also, the categorization is discussed in the literature in a general manner in the manufacturing context, not specifically mentioning any common ways for it in marine engine context.

The third gap identified for this research was that the human and organizational factors are underrepresented in quantitative studies. It is strongly proven that human factors cause most defects and that organizational issues, such as communication, instructions and trainings matter. However, most of the previous DMAIC studies focus on technical causes and under-emphasize the human and organizational root causes. Commonly, studies miss the qualitative insights and focus only on the quantitative data. Also, literature points out that DMAIC works well as an improvement approach but doesn't include discussion on the constraints or reflection on tool limitation.

In response to these gaps presented, the thesis applies a DMAIC methodology in a case study approach to investigate product quality issues in the marine engine industry. By integrating Pareto analysis, root cause analysis techniques (Ishikawa diagram and five whys) and qualitative insights from interviews, the study aims to contribute empirical evidence on how structured quality tools can be combined to support systematic and context-sensitive product quality improvement.

3 Methodology

The main purpose of this section is to provide an overview of the research methodology used. This chapter includes a detailed description of the research design, research approach, and research techniques that are used in the research. Moreover, it describes the methods of data collection, data analysis and interviews. The aim of this chapter is to make sure that the research is transparent, and the readers can understand and recreate the way that the research was performed.

3.1 Research design

The research problem is a core subject in deciding the methods that can be used in the research. There are two different main types of research problems: nomothetical and normative (Helo et al., 2019). Nomothetical type of research problem is commonly asking how things are currently, and normative asks how things should be in the future. To determine which type of the research problem, occur in this research, these questions were explored. In this research the case company wants to understand the root causes of ongoing product issues and to prevent those from reoccurring. Thus, this research is nomothetical and normative, as its core is to understand the current situation and to suggest improvement actions to prevent issues based on the findings.

In this research, it can be stated that neither qualitative nor quantitative methods will sufficiently answer the research questions. Since this study combines data from the case company and from the interviews, research can be stated to use mixed methods. Using mixed methods allows this research to get relevant findings and richer detail of the improvement suggestions (Tegan, 2021). Tegan (2021) points out also other benefits in using mixed methods, such as credibility. Mixed methods adds the value of credibility, because there is more than one method in how the data is collected. It strengthens the validity and reliability of the conclusions of the research. With in mixed methods, there are different designs, such as explanatory sequential design (Tegan, 2021). In that design, the quantitative data is collected and analyzed first and after that, qualitative data comes

to the picture. In this research the idea is to first analyze the case company's data, followed by interviews to explain and contextualize the data analysis findings. Taking these factors into account, it was chosen to conduct this research using mixed methods and explanatory design.

Case study approach is commonly used in industrial management research (Helo et al., 2019). As well as in this research, there is a problem within a case company, the most suitable approach is case study. Helo et al (2019) describes case study as providing a close and deep view on the research problem in a certain environment. Case study approach can be exploratory or design science (Helo et al., 2019). This research can be defined as both, exploratory and design science, because it studies how things are and how to improve the current situation. According to Helo et al (2019) both case study approaches are very pragmatic. This study adopts a case study approach combined with the DMAIC methodology. Figure 3 shows this research's methodology in a simpler way.

One part in this research was conducted with the help of artificial intelligence (AI) tools, the categorization of root causes. The idea behind it was to do it based on the root cause analysis description, but pretty quickly it was noticeable that there wasn't a standardized way in how the root cause was written and described. In some cases, it was easy to understand, for example "poor design" but in some it was a long, very technical description of what have happened. From those technical descriptions it was very hard to understand what really had happened and what actually was the root cause. Even in some cases the description was hard to understand, not only because of the technical approach, but because it was written so unclearly.

Since this RCA description's unclearness was identified, it was decided that for the categorization, artificial intelligence (AI) will be used. Copilot, GPT-5 version, was the AI tool choice for two reasons. First, the case company has an existing license for the service. Second, with the license, Copilot could be used securely with sensitive data. Copilot was prompted to categorize the root causes of the given Excel sheet with suitable categories.

The categories were prompted to Copilot and it was asked to determine the keywords for each root cause category. After receiving the root cause categorization and keyword list, Copilot was prompted to do the categorization again. For the second round, the keyword list and root cause categories were provided to Copilot. Categorization was done two times to provide enough information for the manual categorization.

For this research, DMAIC methodology provides a structured approach to address the given problem; measure and control the quality of products (Helia et al., 2018). The five step process of DMAIC: define, measure, analyze, improve and control, is described in the next chapters.

In conclusion, the method used in this research is mixed methods. The design is chosen from mixed methods designs, which is explanatory sequential design. For the research approach it has been concluded that the best fit for this research is the case study approach, with conducting the research based on the DMAIC methodology. Findings of this research are both normative and nomothetical, due to the stated characteristics of the problem.

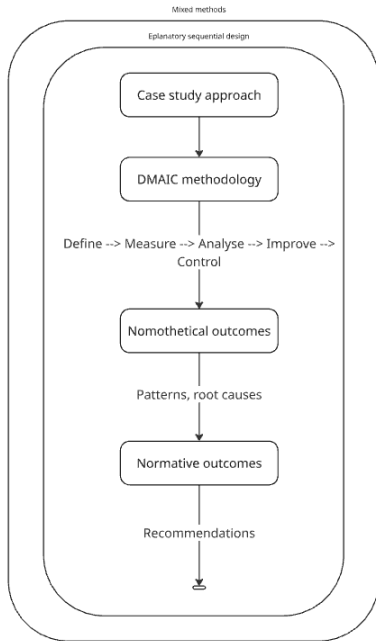


Figure 3. Research methodology.

3.2 Data collection

For the literature review, the data collection was conducted through searches in different academic search engines, such as Google Scholar, Google and Scopus. The publications searched were filtered to be published in the time frame of 2000-2025.

The data collection conducted from the case company was a combination of naturally occurring data and interview data. Naturally occurring data was collected from applications used by the case company, such as Salesforce¹, M-files² and RCpro³. From Salesforce, all of the product improvement process (PIP) projects within the time frame

¹ Salesforce is a core platform at the case company. Its main purpose is to provide a means to achieve customer centricity and the technology to manage relationships and interactions with customers and potential customers. It includes not only CRM (customer relationship management) and sales related solutions but also provides the platform for technical requests, field service, supplier portal, SRM (supplier relationship management), case company on-line customer portal and more.

² M-Files is enterprise content management (ECM) solution that helps organize, manage and track business relevant documents and information. It provides features such as version control, metadata tagging, search capabilities and workflow automation.

³ RCPro is a software where users can implement Apollo Root Cause Analysis methodology by a standardized platform.

of 2020-2025 were retrieved. There were 136 projects within that time frame and that had the Root cause analysis phase done, including only the projects regarding 4-stroke engines with the case company engine type (13 different engines). The data included PIP number, title, risk, start date, end date, issue manager and engine type. From M-files, RCpro and also from Salesforce, the Root cause analysis solutions were added to the Excel by the correct PIP number. The RCAs were written, describing text about the root cause found or a picture of the root cause analysis chart made in RCpro application.

The data also covered the non-conformity costs of the PIP projects in the Excel. Those costs were gathered with the help of a colleague. The non-conformity costs were gathered from a shared drive. Gathering the non-conformity costs required the knowledge of what the costs consists of. It was possible to gather all of the costs of a PIP project from the shared drive by searching them one by one. After the search, a 1500-row Excel sheet was provided with all the non-conformity costs that could be found. Those costs were added to the original data in Excel to the correct PIP number. Not all of the PIP numbers had costs or the costs were big enough that there would have been data about it. Roughly 46 % of the PIP cases' costs were recorded.

The naturally occurring data used in this research is structured, qualitative, and quantitative. The data is organized in a table format, where each row has certain attributes, such as project name, problem description, root cause solution and the cost of the project. Part of the data can be described as qualitative. The problem description and the root cause solution were in text format for that it is qualitative data. In the other hand, the project cost, that was determined to each project in Excel, is numerical data that allows statistical analysis is quantitative data. So, it can be stated that the naturally occurring data is a project-specific, partly qualitative and partly quantitative dataset that is used for this research.

After collecting and analyzing the naturally occurring data, interviews were conducted. Post-analysis interviews enabled getting clarification on the results and getting a more

in-depth analysis of the naturally occurring data. For these reasons, the research design, explanatory sequential design (cf. Chapter 3.1), was chosen. The interviewees are all referred to as experts with identification numbers. Only experts inside the determined top three subcategories were included in the population, which was 12 experts. Population determined means the entire group that was wanted to be analyzed (McCombes, 2019). The sampling was done by probability sampling. Probability sampling means that every member of the population has the same probability of being chosen (McCombes, 2019).

Inside the three subcategories, there were different amount of experts. One expert could have knowledge in one to three subcategories (Table 1). In total, there were 12 experts, and numbers 1-12 were assigned to each to represent them.

Table 1. Experts' division across the subcategories.

Engine structure & power	Cylinder head & valve	Fuel systems
1	1	1
		2
	3	3
	4	
	5	
6	6	
	7	
		8
9	9	9
	10	10
		11
	12	12

To be able to interview from all of the subcategories, it was decided to interview 33 % of the experts from all subcategories individually. The calculation on how many experts of each subcategory would be interviewed can be seen in Table 2. The number was rounded up if it wasn't an even number. The interviewees were determined by a random number generator (*RANDOM.ORG - True Random Number Service, 2026*). Generated numbers were converted into experts' identification numbers (Table 2). All in all, there were seven experts determined to interview. The red numbers indicate that the expert didn't answer

or wasn't able to attend the interview. The green numbers indicate the experts who were able to attend the interviews. In the fuel systems subcategory, the substitute interviewees were determined from other experts by asking who could be the persons to interview. From the first interviewed experts, two other experts were determined to interview and those are not seen in Table 2.

Table 2. Generated experts from each subcategory.

Subcategories	Engine structure & power	Cylinder head & valve	Fuel systems
How many experts?	3	9	8
How many to interview (1/3)?	1	3	3
Random number generated experts	number 1, 9	numbers 6, 12, 5, 3	numbers 11, 2, 8

Before conducting the interviews, the interviewees were asked if they were willing to participate in them. Background information was provided beforehand. The interviews were semi-structured. In other words, some questions were prepared, and themes were prepared, but not in a strict format (Appendix 3). This gave the interviewees the opportunity to discuss subjects that they consider relevant (Jianbin, 2024). Also, semi-structured interviews give the interviewer the opportunity to guide the conversation towards topics that are relevant in that specific interview. Beforehand, determined questions and themes were provided for the interviewees before the actual interview. Finally, there were 7 experts who were interviewed (Table 3).

Table 3. Interviewees identification numbers.

Interviewed experts identification numbers
2
3
5
9
12
13
14

3.3 DMAIC Methodology in Case Study Approach

The DMAIC methodology was chosen because it provides a structured data-driven approach for understanding quality problems and reducing recurrence. For the case study approach, DMAIC offers a way to clarify the defect situation, create consistent categorization practices, and support long-term improvement of quality processes.

In this case study approach research, the DMAIC phases progressed through the following key activities. The tools and techniques used in the key activities were chosen because of their suitability for the research, qualitative and quantitative data collection, the prioritization need for subcategories and for the investigation of underlying root causes. These activities are described more in detail in Chapter 4.

1. **Define phase:** In the define phase, the problem itself was identified. Stakeholder analysis and project charter were created to clarify the purpose, scope, timeline, and goals of the research. The define phase, particularly the project charter, was important so that it was possible to clarify research scope and timeline, and to keep according to those.
2. **Measure phase:** In the measure phase, the current state of the defect reporting was examined by collecting data from the case company. Also, the quality of the data was analyzed, and a categorization model was developed. The main

category for further research was identified. The measure phase was very important to this research, because the case company didn't have a clear view of the current situation regarding categorization, what is the largest issue category and what data is available, and is it good quality.

3. **Analyze phase:** Subcategories were identified and applied within the main category. A Pareto chart was used to identify the top 3 most significant subcategories. The top 3 defect types were explored in more depth to identify potential root causes. Qualitative interview data were analyzed manually by thematic analysis to be able to find the recurring themes to focus on. Tools such as the Ishikawa diagram and 5 Whys were used to synthesize the qualitative interview data and to understand the underlying factors affecting the defect occurrence. The use of Pareto analysis was a request from R&D management team because it is a widely used and known tool inside the case company. Also, the 5 whys and Ishikawa diagrams are commonly known in the case company, and those were requested to use as well. Chosen tools were suitable for the R&D management team's requests and needs as well as suitable for the scope, timeline, and result limitations of this research.
4. **Improve phase:** Improvement suggestions from interviews were identified. Three key improvements were determined according to interviews and the data analysis. The improvements focused on three different themes to be able to provide widespread changes for better product quality.
5. **Control phase:** For the improvement suggestions, control plans were determined. The aim was to answer the question "How can we ensure that the improvements continue after this research?".

3.4 Reliability and validity of research

The reliability and validity of this research were ensured in three ways. The first way was to use literature only from academically reliable resources. These reliable resources were used to give the reader an understanding of the background of the study. Literature from different resources were combined and used as sources to provide a full picture.

Secondly, the reliability and validity of this research were ensured by collaboration. This research was done in collaboration with the case company and its professional employees. The case company and its professionals have a strong background in the industrial manufacturing field and reliable performance across the industry. Also, this research was reviewed by the case company supervisor to ensure that it is aligned with the company and to improve its reliability and validity.

Thirdly, the reliability and validity of this research was ensured by using DMAIC methodology. In DMAIC, different measurement and analysis tools are used (Harkhoe, 2025). Commonly used and known tools embrace research's reliability and validity.

4 Findings and the Application of DMAIC

In this chapter, the five DMAIC (define, measure, analyze, improve and control) phases are described in detail. It represents how DMAIC methodology was applied in the case company systematically to examine and improve the management of product defects. Each phase has its own chapter, which describes what tools and techniques were used in it. Chapter 2.6.1 discusses the phases of DMAIC in a general way and what they mean. This chapter includes only the description of the case study's use of DMAIC phases, not the general explanation or meaning of it.

4.1 Define phase

In the define phase, it was necessary to establish the foundation for this research by articulating the problem, setting the goals for the project, and identifying the important stakeholders involved. The key activities and tools used in the define phase are problem definition, stakeholder analysis, and project charter.

4.1.1 Problem Definition

The case company experiences a high volume of occurring and reoccurring product defects. The company's current practices for handling these defects are insufficiently systematic. Product issues aren't consistently categorized, and their underlying causes aren't analyzed in sufficient depth. In addition, the collection and documentation of defect-related data aren't in an optimal state. The data is often incomplete, inconsistently recorded and lacks the structure, clarity and variability needed for meaningful analysis. As a result of this, the case company lacks a clear understanding of defect patterns, root causes, and improvement opportunities. This leads to reoccurring issues, ineffective corrective actions, and limited ability to prevent defects from happening in the first place.

The absence of structured categorization, effective RCA, clear collection of data and data-driven improvement methods prevents the company from developing a

comprehensive view of where and why defects happen in the first place. Without acknowledging this, the company's continuous improvement efforts remain fragmented, unreactive, and unable to support long-term quality development. Lastly, this undermines product reliability, internal efficiency, and customer satisfaction.

4.1.2 Stakeholder Analysis

The stakeholder analysis was conducted to identify individuals and groups who can influence or are affected by this research. Also, to understand the stakeholders' level of power and interest towards this research. By doing the stakeholder analysis it was possible to plan communication and engagement with the stakeholders to reduce confusion and ambiguity.

Before choosing the right model for this research, an investigation about commonly used frameworks for stakeholder analysis inside a DMAIC project was conducted. Three different commonly used frameworks were studied: Power/interest grid, Influence/impact matrix and Saliency model (Peterka, 2024). After the investigation, the saliency model was chosen. The saliency model was chosen because it is often used for complex projects which are influenced by multiple stakeholders (Peterka, 2024). This describes this research.

The Stakeholder Saliency model was created by Ronald Mitchell, Bradley Agle and Donna Wood (1997). The stakeholder saliency evaluates stakeholders' relationships including attributes power⁴, legitimacy⁵ and urgency⁶. Those three attributes are modelled in Figure 4. Inside the attribute circles, stakeholders are located in a place that describes their

⁴ Agle et al. explains power as the power a stakeholder has in the relationship to affect it and to express its own desires. They state that power isn't a steady state but rather a variable and that's why it can be gain or lost.

⁵ Agle et al. explains legitimacy as Suchman (1995) has defined it. Legitimacy is a wanted social good, that can define and decided differently depending on the organization. It is larger concept than just a person's own feeling.

⁶ Agle et al. explains urgency by defining two attributes that have an effect to it. Those are the stakeholder's relationships time-sensitive nature and the relationships criticality to the stakeholder.

relationship towards the research. Here are the most important stakeholders and their relationship towards this research described:

- **Dominant (power + legitimacy):**
 - **Company supervisor:** Has formal legitimacy and has power for data access and project scope.
- **Dependent (legitimacy + urgency):**
 - **Line manager:** Has a legitimate interest because the research may affect operations or employees and wants insights sooner.
- **Definitive (power + legitimacy + urgency):**
 - **R&D management team:** Has high power on affecting research decision making. Legitimacy for the research alignment with strategic business needs and urgency with the strategic deadline.

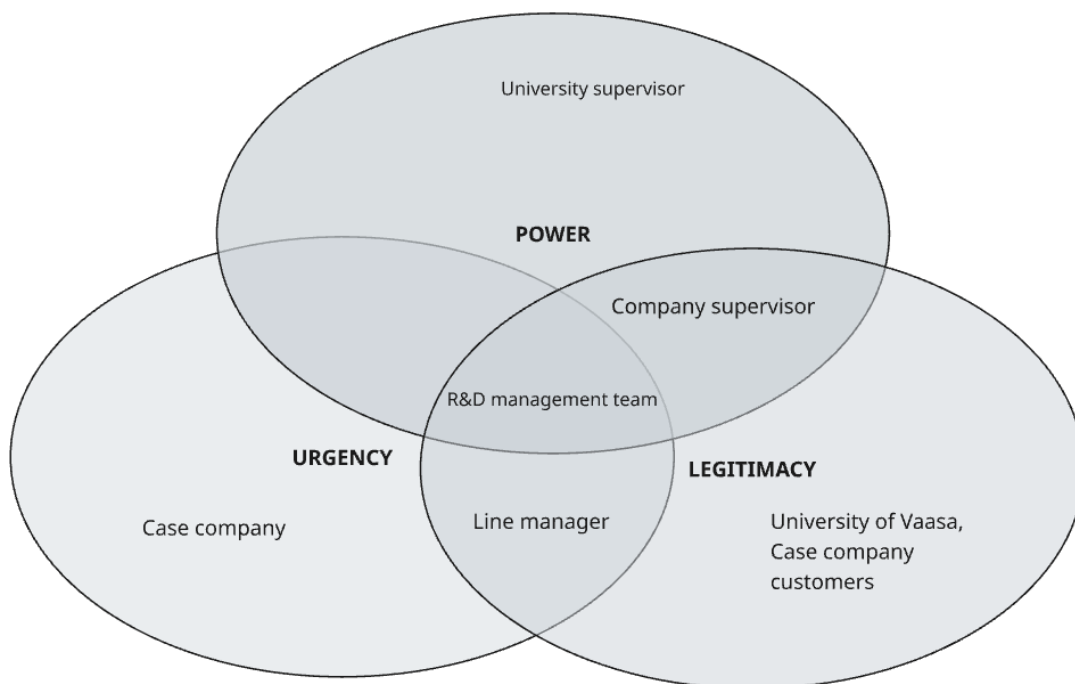


Figure 4. Stakeholder Salience with relevant stakeholders (Agle et al., 1997).

For each stakeholder their level of influence, engagement strategy and their areas of interest have been analyzed and reflected to the salience framework. Analyzing the stakeholders; University of Vaasa and university supervisor also the case company and

its customers, it was stated that all of them have a low level of influence. They all only affect one of the three attributes, which leads to their salience of them being low. In the other hand, line manager and company supervisor were analyzed to affect two attributes. This raises their salience to be higher than what it would be with just one attribute. The stakeholder R&D management team was analyzed to affect all three attributes: power, legitimacy and urgency. This leads to its salience being the highest of the stakeholders.

Not all of the places in Figure 4, got a stakeholder. In this research, the determined stakeholders were all analyzed, and based on the analysis, the salience was selected. In conclusion of the stakeholder analysis, it can be stated that this research has a clear and important mandate to prioritize R&D management teams' needs and wants as it has the highest salience.

4.1.3 Project Charter

The project charter for this research (Appendix 1) was made by using a template from Smartsheet, made by Eby Kate (2019). The project charter is used as a guiding document for the research. It includes the description of general information, problem overview, project scope, tentative schedule, resources and lastly risks, constraints and assumptions. Main parts of the project charter were to identify the project scope and the risks of the research.

4.2 Measure phase

In the second phase of DMAIC methodology, measure, the goal was to establish a reliable baseline of the current defect situation. The measure phase quantifies the problem that was defined earlier in the define phase, by examining defect frequency, types, severity and distribution. In this research, the measure phase consists of these five points: current state, data quality assessment and limitations and categorization.

4.2.1 Current state, Data Quality Assessment, and limitations

The current state of the problem was defined from the data that the case company had. How and what data was collected was explained in Chapter 3.2. From the data retrieved, the lead time of a single project was calculated, as can be seen in Figure 5 as an example. From those lead times, the total lead time of all of the projects was calculated to be 138113 days. Total lead time of 138113 days converts approximately to 378 (378.39) years and there were 136 projects in that list. It must be noted that many projects can be ongoing at the same time. Also, weekends or holidays weren't reduced from the lead time. If the project wasn't finished until the current state analysis, the lead time was calculated from a forecast of the end date done by the project team.

D Start date	E End date	F Lead time (days)
2021-04-26 00.00.00	09/02/2023 0.00	654,00

Figure 5. Example of project-specific lead time in days.

To clarify the current state more, it would have been useful to determine the defect rate. This wasn't possible or suitable from this data collection, because there was no data about the fact that how many engines are affected by one PIP project. It wasn't possible to compare the impact of the problem per engine to how many of those same types of engines have been manufactured. Also, because of this information being missing, calculating the sigma level wasn't possible. Sigma level is calculated as the defects per million opportunities using data of number of defects observed, number of units and defect opportunities per unit. It is not suitable for this use because there isn't enough precise and detailed data available about the scope and impact of the defects observed. In some of the cases there was data or information available about the frequency of the issue. Unfortunately, there wasn't a standardized way how it was documented or was the

meaning of it even correctly understood. It was decided not to use that data, it being too unclear and unreliable

In the beginning of the measure phase, it was noticed that the company uses some kind of categorization for the root causes. The categories used were design, supplier quality and manufacturing/internal operations (Figure 6). Only approximately 34 % of the root causes were categorized (90 of 136 weren't).

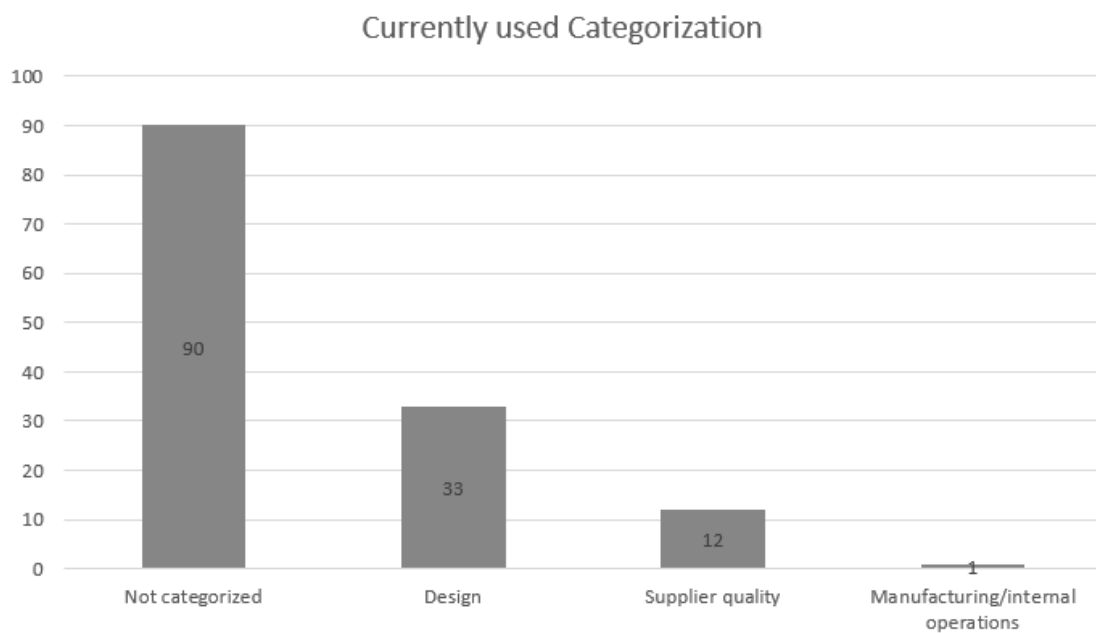


Figure 6. Current state of the categorization.

4.2.2 Categorization

One of the objectives of this research was to categorize the root causes. Since the RCA description unclearness was identified, it was decided that for the categorization, artificial intelligence (AI) will be used as described in Chapter 3.1. The categories were brainstormed in the starting meeting with the R&D management team and with the help of the categorization the case company already uses. Copilot was prompt to determine keywords for each category and use them when categorizing. The keywords of the selected

categories can be seen in Appendix 2. For the categories, these were chosen in the starting meeting:

1. Manufacturing: Selected when failures are caused by errors in production processes. Meaning that something went wrong while making the part.
2. Design: This category is used when the root cause originates from how the component or system was designed.
3. Assembly: Selected when failures are caused during putting the parts together. Meaning that the parts are correct, but the way they were assembled caused the failure.
4. Supplier: Used when the failure originates from the suppliers' materials, parts, or processes. Meaning that the failure comes from outside the manufacturer.
5. Other: Used when the data is insufficient or too unclear to classify properly, even with keywords.

After the Copilot had given the categorization and keywords, it was prompted in a new conversation to do it again. This time, the keywords were also provided to it. Copilot provided an excel that had the chosen category and the keywords it was triggered by. This data, with the first categorization, was added to the Excel data sheet. In both uses of Copilot, it was prompted not to use artificial intelligence inference, only coding and other ways that can be shown and proved. Copilot was used just to help and guide the categorization, not to do it for us. It provided category options and reasoning for those categories.

After Copilot's categorization work, all the cases were manually reviewed to confirm the category. In some cases, the manual review changed the initial category. The detailed process chart of the primary categorization was made to visualize the categorization (Figure 7). All individual categorizations follow the same steps from the process chart. The idea behind it was to think to which department the repairing of the root cause belongs to. If suitable category wasn't found on the first round, as many rounds as needed was made to be able to categorize all of the root causes.

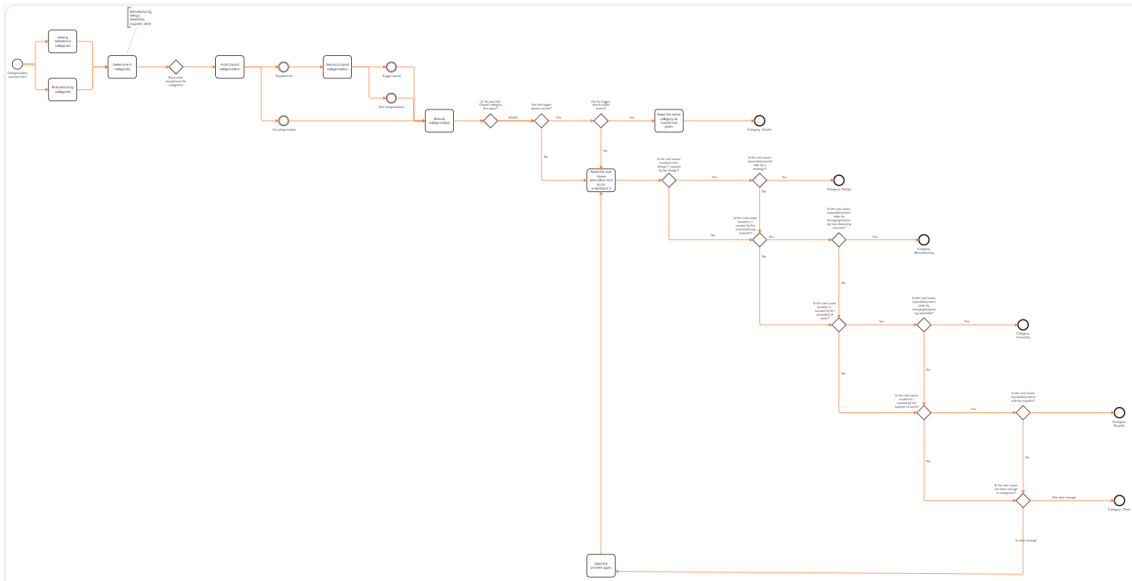


Figure 7. Categorization Process Chart.

In Figure 8, can be seen how the root causes were categorized in all three different ways; 1st copilot, 2nd copilot and manual. Design category was the largest of the categories.

1st Copilot Categorization		2nd Copilot Categorization		Manual Categorization	
Category	Count of PIP number	Category	Count of PIP number	Category	Count of PIP number
Assembly	20	Assembly	6	Assembly	6
Design	66	Design	53	Design	84
Manufacturing	41	Manufacturing	43	Manufacturing	26
Other	4	Other	2	Other	9
Supplier	5	Supplier	8	Supplier	11
Grand Total	136	Uncategorized	24	Grand Total	136
		Grand Total	136		

Figure 8. Differences between Copilot and manual categorization.

After the successful completion of categorizing the root causes, it was time to search and find the most critical reason (=category) leading to defects. This was conducted by calculating different factor norms. A table was made from the data in the Excel, as can be seen in Table 4. The columns count norm, Cost norm and Lead time norm were calculated by dividing each category's value by the grand total. With this we got the counts and sums normalized so that they are comparable on the same 0-1 scale. The normalization of data was done because the case company's non-conformity costs were defined

as internal data that should not be published. Later on the non-conformity costs are always presented as percentage shares of the total sum of costs.

Table 4. Norms calculated across the categories.

Category	Count norm	Cost norm	Lead time norm
Assembly	4,41 %	0,10 %	3,59 %
Design	61,76 %	67,12 %	63,91 %
Manufacturing	19,12 %	19,02 %	19,53 %
Other	6,62 %	5,36 %	5,58 %
Supplier	8,09 %	8,40 %	7,40 %
Grand Total	100,00 %	100,00 %	100,00 %

The design category had the highest share of all factors calculated (Table 4). Manufacturing had the second-highest share in each factor. From these described calculations, it was chosen to pursue to the analysis phase with a more in-depth analysis of the Design category. Deeper analysis for the design category was approved by the R&D management team in a midterm thesis meeting.

4.3 Analyze phase

In the third phase of the DMAIC methodology, analyze, the key thing is to identify the most critical inputs that are leading to defects. In this research, to pursue the analysis phase, it was needed to subcategorize the previously determined main category. With subcategories, it was possible to dig deeper into the category design and determine the critical reasons inside of it that are leading to quality issues.

In the same midterm meeting with R&D management that the main category was approved, a discussion about the subcategorization was also held. Three different perspectives to it were discussed:

1. Subcategories as per phenomena: material, lubrication, temperatures, etc.
2. Subcategories per expertise area: engine structure, cylinder head, valve mechanism, etc.

3. Subcategories as per process step: design guidelines, missing design validation, etc.

In the discussion, it came up that of course all of these would be relevant perspectives to analyze, but within the time frame of this research, only one could be selected. Subcategorization was discussed in four different meetings with colleagues. In three of them, subcategorization by expertise area was brought up as the best choice. The reasoning for it to being the most suitable was that it is used in the case company's FMEA and in monthly notification reports. By these discussions, subcategorization by expertise area was chosen. All steps of the subcategorization were visualized to a process chart (Figure 9).

The case company has nine expertise areas:

1. Engine structure & power
2. Running gear
3. Ancillary systems
4. Cylinder head & valve
5. Turbocharging
6. Gas systems
7. Fuel systems
8. Technical advisor
9. Materials and tribology

Expertise areas technical advisor and materials & tribology are support functions, not specifically areas that are responsible for any component. Because of not having component liability, technical advisor and materials & tribology weren't taken into subcategories at this point. All in all there were 7 subcategories.

Before being able to start subcategorizing, it was needed to clarify the where the issues originated and what component was the liable one. This was done in to an Excel sheet by reading the root cause analysis description and the title to determine what is the component in this situation. In this process it was noticed that Salesforce had a section

for “DLC Code Group”. It was a number and a group that the issue regarded or belonged to. That information was also gathered to the Excel just in case, if it would give some help at some point.

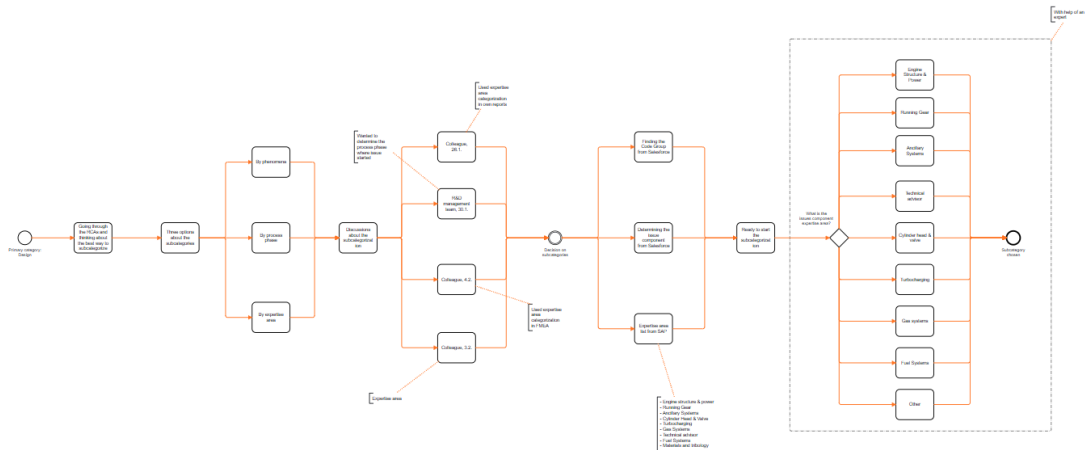


Figure 9. Subcategorization process chart.

It was needed to have a lot of knowledge of the engine components as well as the case company’s division of expertise areas to be able to do the subcategorizing. A lot of help from a colleague was gotten, to get the subcategorizing done correctly. Knowledge about the expertise areas and components belonging to a specific area was obtained. With this help, it was possible to successfully complete the subcategorization. The summary of the subcategorization can be seen in Table 5. In it can be seen all eight subcategories and the amount of cases inside each subcategory as well as the sum on non-conformity costs of the subcategory. As seen in Table 5, some of the cases were subcategorized as other. Reasoning for the subcategory other was that the issue wasn’t the component itself, more over the:

- Automation and software (5)
- Vibration (1)
- Delivery (1)
- Related to engine tools (1)
- Design (2)

- Used wrong (1)
- Performance (1)

These different reasons weren't so impactful to the big picture, so they all were subcategorized as other.

Table 5. Subcategory's count, lead time and sum of non-conformity costs.

Subcategory	Count of PIP number	Sum of Lead time (days)	Sum of NC Cost
Ancillary systems	4	4366	3,60 %
Cylinder head & Valve	19	18609	21,81 %
Engine structure & power	5	4502	21,24 %
Fuels systems	14	19681	26,44 %
Gas Systems	9	9190	4,77 %
Running Gear	5	7245	12,58 %
Turbocharging	16	15602	9,25 %
Other	12	9070	0,32 %
Grand Total	84	88265	100,00 %

Before moving on to the Pareto analysis, it was checked that if there were big differences in the subcategories between small, medium and large bore. From Table 6, the subcategory division between engine sizes can be seen. The biggest subcategories filtered by engine size were:

- Large bore: Cylinder head & valve with 15 cases from 47
- Medium bore: Fuel systems with 7 cases from 31
- Small bore: Other with 3 cases from 6

The largest sum of lead time subcategory filtered by engine size was:

- Large bore: Cylinder head & valve approx. 15 800 days
- Medium bore: Fuel systems approx. 12 500 days
- Small bore: Other approx. 2600 days

The largest financial impact subcategory filtered by engine size was:

- Large bore: Engine structure & power 37 %
- Medium bore: Fuel systems 53 %
- Small bore: Gas systems 100 %

All in all it can be said that there are differences between the most impactful subcategories by engine size. It was decided to take the S/M/L bore division into account only in the Pareto chart (Figure 10) to describe the divisions inside subcategories.

Table 6. Division of subcategories according to S/M/L bores.

Bore definition		Count of PIP number	Sum of Lead time (days)	Sum of NC Cost
Large Bore		47	46423	57 %
	Cylinder head & Valve	15	15825	29 %
	Engine structure & power	5	4502	37 %
	Fuels systems	6	6395	8 %
	Gas Systems	4	3695	0 %
	Running Gear	4	5672	17 %
	Turbocharging	8	7382	9 %
	Other	5	2952	0 %
Medium		31	37116	42 %
	Ancillary systems	3	3656	9 %
	Cylinder head & Valve	4	2784	13 %
	Fuels systems	7	12491	53 %
	Gas Systems	4	4904	10 %
	Running Gear	1	1573	6 %
	Turbocharging	8	8220	9 %
	Other	4	3488	1 %
Small		6	4726	1 %
	Ancillary systems	1	710	0 %
	Fuels systems	1	795	0 %
	Gas Systems	1	591	100 %
	Other	3	2630	0 %
Grand Total		84	88265	100 %

4.3.1 Pareto Analysis

After the successful completion of determining the most important category and sub-categorization to it, it was time to search and find the top three most critical reasons (=subcategories) leading to defects. To find these critical reasons, Pareto analysis was conducted. Before conducting it, R&D management team could provide input on the way Pareto analysis is implemented in the midterm meeting that was held. Meaning that they were provided with four different factors from which the Pareto analysis would be based on and they would need to make a decision on which factor to pursue. Those four factors were:

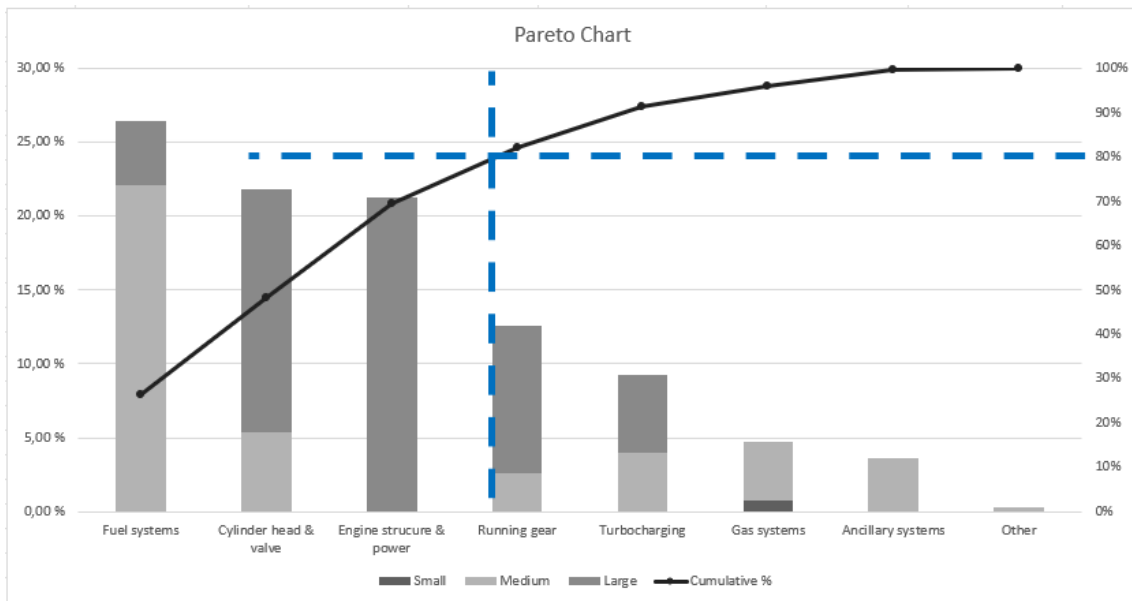
- Largest categories: meaning the top three most common categories.
- Financial impact: meaning the top three most expensive categories.
- Lead time contribution: meaning the top three most significant in terms of lead time.
- Risk: meaning the top three biggest risk contribution categories.

In the meeting, it was discussed that both category size and financial impact would be important to analyze. Category size would be interesting, because it would answer to questions like “What are the most common types of quality issues?” and “What are the main reasons leading to quality issues?”. Financial impact factor would be interesting because it could tell us what types of issues are the most expensive and what could be the financial benefits of preventing those issues from happening. In the end of the meeting, it was decided to pursue the Pareto analysis with the factor of financial impact.

The Pareto analysis was conducted by calculating the S/M/L bores non-conformity costs sums and cumulative percentages of all subcategories (Table 7). From these calculations, the Pareto chart was drawn (Figure 10). The Pareto chart shows that fuel systems, cylinder head & valve and engine structure & power are the most significant contributors. These three most significant contributors account for approximately 80 % (69,49 %) of the total cumulative impact, as indicated by the blue horizontal line. Fuel systems alone represent the single largest contributor, driven mainly by medium and large bore cases. Similarly, cylinder head & valve and engine structure & power show a substantial contribution dominated by large bore cases. In contrast, running gear, turbocharging, gas systems, ancillary systems, and other subcategories contribute relatively little to the overall total. Although these issues do occur, their cumulative financial impact remains low when compared to the leading subcategories. This supports the Pareto principle, according to which roughly 20% (37,5 %) of causes are responsible for 80% (69,49 %) of the effects. The TOP3 subcategories are determined according to the Pareto chart: Fuel systems, cylinder head & valve and engine structure & power. Focusing on these areas is likely to proceed greatest reduction in total non-conformity costs.

Table 7. Pareto analysis on subcategories.

Subcategory	Small	Medium	Large	Total from subcategory	Grand Total	Cumulative %
Fuel systems	0 %	83 %	17 %	100 %	26 %	26,44 %
Cylinder head & valve	0 %	25 %	75 %	100 %	22 %	48,26 %
Engine structure & power	0 %	0 %	100 %	100 %	21 %	69,49 %
Running gear	0 %	21 %	79 %	100 %	13 %	82,07 %
Turbocharging	0 %	43 %	57 %	100 %	9 %	91,32 %
Gas systems	16 %	84 %	0 %	100 %	5 %	96,08 %
Ancillary systems	0 %	100 %	0 %	100 %	4 %	99,68 %
Other	0 %	100 %	0 %	100 %	0 %	100,00 %

**Figure 10.** Financial impact Pareto chart.

4.3.2 Analysis of the interviews

The interviews were conducted to be able to find the underlying root causes. Interview questions were semi-structured to make the conversation more open and adaptable to the discussion (Appendix 3). Interviews were recorded and transcribed to be able to analyze them afterward. Interview analysis was done as a thematic analysis which means collecting themes or central topics that connect the interview answers together (Saaranen-Kauppinen & Puusniekka, 2006). Thematic analysis was done manually going through the transcripts and recordings and collecting themes into an excel. A

quantification table was made to observe which aspects and themes of the data are most central (Table 8).

Table 8. Themes and subthemes of discussion.

Theme of discussion	Subtheme of discussion	In how many interviews
Supplier management	PQAP/CCPAP	7
Supplier management	Communication	5
Supplier management	Component changes	3
Supplier management	Demand changes	1
Supplier management	Internal Quality requirements	1
RCA process	Documentation, not structured	7
RCA process	Information sharing	5
RCA process	Clearness	2
RCA process	Focus on technical, not process	2
Design process	FMEA	5
Design process	Design guidelines	4
Design process	All interfaces of design	3
Design process	Reuse of existing designs	2
Design process	Cost focus	2
Design process	Risk assessment	2
Testing and validation process	Short FAT	5
Testing and validation process	Limited testing capacity	5
Testing and validation process	Not all variants possible to test	3
Testing and validation process	Simulation	3
Testing and validation process	Cost focus	2
PIP Process	Complexity of issues	5
PIP Process	RCA starting point, Technical service	4
PIP Process	Responsibility not clear for early signals	3
PIP Process	Criteria for PIP	2
PIP Process	Proactive following	2
PIP Process	Definition of PIP	1
PIP Process	Current categorization	1
Lessons learned process	Learning from mistakes	4
Lessons learned process	Motivation for LL	4
Lessons learned process	At the end of PIP	4
Lessons learned process	Responsibilities of LL, sharing it	2
Lessons learned process	Instructions, documentation	2
Lessons learned process	What it really means	2
Quality control	Inspections overloaded	4
Quality control	Quality checks	4
Quality control	New components control	3
Quality control	Supplier inspections	3

Seven themes came up in the interviews. To get a better understanding of what was discussed regarding the theme, different subthemes were determined. The number of

subthemes wasn't restricted in any way, so those subthemes that were mentioned in one interview were also included. Quotes from the interviews regarding each theme were collected to prove that the theme was brought up. Also, to portray the had discussion (Table 9).

Table 9. Quotes related to the themes discussed.

Theme of discussion	Quotes from discussed theme	Quotes from discussed theme...	Quotes from discussed...
Supplier management	"Many times happens that the supplier is given with a proper design and also with proper qualities, but if you go there and audit what they are actually doing, it is not really fully in line with what we asked. " Interviewee 2	"Then I would say that we would need to share more the concerns with supply management, still a bit more info from field to supply management ... A lot of joint work together, teamwork with the supply management, with the strategic, with the issue manager, with the quality part, all together to facilitate the bottlenecks to bring experience, to go over the bottlenecks that we find. " Interviewee 13	"For example, pipes from a gas pipeline and that drawing contains sub-drawings. And there is a small change to the sub-drawing, it does not appear in the main drawings at all or necessarily to that supplier. That information may be that it goes somewhere or not. They might have some software from where we send it to them or it goes only by email and I think that communication is very bad if it is at this level, these changes should really be reviewed in more detail with that supplier. " Interviewee 5
RCA process	"I would say that it is really terrible how have they been reporting the RCA and it is in many different ways and it is really confusing what you get and you might need to really go and learn what the root cause really was. " Interviewee 14	"Still information are in reports, in mails, not structured. We have a bit of a difficulty, even if we have set up a standard to be filled in with the statistic and data, that's not so one-to-one easy to have. And several of this information are in reports, and you have to go through reports and collect those. " Interviewee 13	"Root cause analysis was a bit poor in the quality. And if in some cases I may understand that it may be challenging to get all the details, in other cases I noticed some frustration and so forth from the team. So it is also personal things that may happen in between. " Interviewee 2
Design process	"Many many many little things that would be needed to take into account and to done correctly, also the minds of people to think about every little detail in the desing. " Interviewee 5	"We would always need to remember to do the FMEA and think how this change is going to affect on something else and in which way it can come up later on in the future. " Interviewee 3	"We have to increase a risk assessment on everything we do, because if you do a change, you can introduce consequential risks. " Interviewee 13
Testing and validation process	"So many times we can reconduct on some other issues, for example people not tightening with the proper tightening torque. " Interviewee 2	"If we cannot test engines with the real variants and factors it is really hard to know what is going to happen when the engine is running at the customers. " Interviewee 9	"We are not good at updating our guiding documents for example according to what is discovered in FAT, because of time constraints, prioritization, work load, etc. " Interviewee 13
PIP Process	"We wait until small risks are realized, that risk there, and then we act. It should be done without a fear of raising red flags and knowing who'll take the responsibility of it. We don't have that. Then it's just swept under the rug and if something comes up, it'll be fixed later. " Interviewee 5	"Check it (tool) for updates but always inside the large bore engines. Together with the medium bore or small bore engine we basically don't have any anything so I can if I have time, I can go through using the PIP tool we have. We can explore the other cases, but basically, no, there is not so much link between large bore and medium bore or small bore. " Interviewee 12	"The communication is often a bit bad. They don't necessarily know that if we have a problem like this, it's been in smaller engines before. Then it can take 2 years and we'll see the same problem in the large bore engine, and then they wonder for a year, and then someone says, but we did this years ago. " Interviewee 14
Lessons learned process	"At the end, we have LL, but it is done in half an hour when everyone is under some kind of pressure and this is really interesting, so there is that, yeah, we worked very hard, there was a good team spirit and other things, but really, what did we learn. " Interviewee 14	"LL is how the case went, but then we need to know, when it's distributed, to whom or to whom the problems are distributed, is it liked to be solved or just for information and so on, it's like that. " Interviewee 3	"We should be able to deal with these current problems because honestly, like you said, sometimes you have to look in the mirror, whether it comes from us or from the supplier. More like looking back at the past and reporting better, what we have learned now. " Interviewee 14
Quality control	"But I know that the quality department now have a very large backlog, because, for example, we have in some cases an issue with the supply of components, so they have to check 100% of, so all the components needs to be checked by them, and this requires time. And if you focus on this component, you cannot check also the other ones. So maybe on the other ones, they start to come out as other issues. You are sure on one side, but on the other side, something is going wrong. So maybe it should be needed to check also how the supplier themselves are checking the quality. " Interviewee 12	"Not time or possibility to quality inspection to production because of the overload of X factory (name of the factory modified). " Interviewee 9	"Then there are those that we have this PQAP, CCPAP and all that, and somehow implementing them is quite tricky. It seems like no one really knows what to do with them. We all think that it's the Supply management that takes care of it, yes, the supply management and the expert are the main ones, but they also have so much work that it's a bit of a struggle. " Interviewee 5

Supplier management and RCA process were brought up in every interview. Documentation and PQAP/CCPAP were the most widely discussed subthemes. Those were related

to the most widely discussed themes. From all of the interviews, it was obvious that the themes and subthemes are connected to each other and have an effect on each other. For example, between these two issues, there is a connection; it was mentioned that the supplier quality isn't always good, then it was also mentioned that communication and collaboration internally and externally about supply management-related matters isn't always working and is causing bigger issues. To find these relationships and to find the true underlying root causes, the root cause analysis was conducted in the next chapter.

One critical theme of the interviews was improvement suggestions. Before conducting the root cause analysis, thematic analysis for the improvement suggestions from the interviews were made. Interview improvement suggestions were categorized to see what the most critical points are to focus on (Table 10). The suggestions that were discussed among only one interviewee, weren't taken into Table 10. Only suggestions that were mentioned by at least two interviewees were taken into consideration. As a reference, the quotes of the improvement suggestions were collected into a table (Table 11).

Table 10. Interviews improvement suggestion themes.

Improvement suggestions discussed	In how many interviews
Embracing, motivating, possibilities for collaboration and information sharing	6
Better/more supplier quality, control/inspections, CCPAP, PQAP	4
More testing/validation/vibration measurements	3
Clearer instructions, helping guidelines, FMEA, explanations for instructions, standards for documentation and reporting	3
Learn from history, learn from mistakes, more focus on the LL	3
Increase internal quality inspections	2

Table 11. Quotes regarding the discussed improvement themes.

Improvement suggestions discussed	Quotes regarding improvement suggestion theme
Embracing, motivating, possibilities for collaboration and information sharing	<p>"I can add again that it is fundamental that people, colleagues can work together without any restriction and be collaborative with each other and try to answer to the question as soon as possible. " Interviewee 12 "Sometimes we tend to work in silos, so we have the R&D expert, we have the technical service,, we have us in the middle ... if we would work together from the beginning, I think we could prevent different things. This is I see as preventive if we together put more effort. " Interviewee 9 "To give some availabilities on people talking to each other, so working together closely. So maybe this thing that we have to do all these things through teams and not peer-to-peer in person. " Interviewee 2 "We would need to start to think at regular follow-up of what is happening. cross-functional, cross-engine type. " Interviewee 13 "Raport also what is workin on the field to reinforce positive culture. " Interviewee 14 "Maybe to have this open forum for corss-functional discussion. " Interviewee 5</p>
Better/more supplier quality, control/inspections, CCPAP, PQAP	<p>"More supplier quality control and FMEA and of course of course you can always look in the mirror too. " Interviewee 3 "More checks to the suppliers ways of working and how producing the components. " Interviewee 12 "It should be clear how to perform CCPAP/PQAP and whos responsibility it is. Also why we are doing it. " Interviewee 5 "Try to look at other options regarding suppliers so they don't have so much power over us as a single supplier. " Interviewee 9</p>
More testing/validation/vibration measurements	<p>"Having more testing, having more time also for FAT, in my opinion, is another big version on how to mitigate those issues. " Interviewee 2 "We should validate the products more. And yeah, and we know that for this, there are physical limits. " Interviewee 13 "All kind of vibration measurements and tests are great to have. " Interviewee 3</p>
Clearer instructions, helping guidelines, FMEA, explanations for instructions, standards for documentation and raporting	<p>"Producing instructions, so that, yeah, you are instructing how to do the work, how to preserve the parts. Care in instruction, instructing people how to do the work, maybe one explanation more than one explanation less. " Interviewee 13 "Such a design review is there just like there in CCPAP or there it is just like just one step there that it would actually use the component expert, the designer and the manufacturer through, that what is this component manufacturability and what are the critical dimensions and functionalities. What should be here now, that they also know what to pay attention to just like between the covers or the cover machinery, that we know that okay these what must at least hit property and in this order it would be worth, their machines that they are OK, that maybe it would be with what where we could still improve. " Interviewee 14 "We would always need to remember to do the FMEA and think how this change is going to affect on something else and in which way it can come up later on in the future. " Intreviewee 3</p>
Learn from history, learn from mistakes, more focus on the LL	<p>"Learn from similarly done design to other engines, not always inventing new things. " Interviewee 12 "We should be able to deal with the issues as they are and face the issue, say what went really wrong. " Interviewee 14 "LL is just a word, find concrete what it means what it gives and to find an concrete explanation for it. " Interviewee 9</p>
Increase internal quality inspections	<p>"And of course, also quality inspection in production is important to avoid issue and also pay attention about known issue that are repeating every now and then during the design phase, because, for example, a solution of a typical problem is already solved on one engine, but on another engine type, there is another designer or design manager that invent again another solution that does not work. " Interviewee 12 "We have to increase a risk assessment on everything we do, because if you do a change, you can introduce consequential risks. " Interviewee 13</p>

It was clear that interviewees wanted an improvement action from the case company that would embrace, motivate, and bring possibilities for collaboration and information sharing. Inside this improvement theme, there were couple interesting concrete

suggestions: providing a cross-functional forum for open and easy discussion, and to report also what is working well.

The second most brought up theme regarding improvements was the supplier quality-related improvements. One of this research's objectives was to provide concrete improvement suggestions that the case company can internally do. The case company can't control the external supplier. Taking this into account, the suggestions regarding internal actions were only brought to the analysis. For example, it was mentioned that the case company supplier processes CCPAP and PQAP aren't clear or known by everyone. Taking improvement action towards this, can be done internally in the case company. It's quite close to the improvement theme about instructions, guidelines, explanations and standards for documentation.

The suggestions related to more testing and validation were widely mentioned. It was also mentioned that it has limits, such as physical limitations. This is a good to note improvement theme, but this research won't analyze it further, because of the physical limitations. This research focuses on improvement suggestions that can be done with the current tools and physical locations.

There were also a couple other interesting themes and improvement suggestions discussed in the interviews. These were brought up by single interviewee, but the author found them interesting and useful for this work to highlight (Table 12). These quotes gave the author wider understanding of the case company's situation towards product quality issues, the ways of working and steps of processes that are allowing quality issues to occur. As they did not contribute to the improvement themes determined, they are presented singly. However, these quotes are used in the concluding chapter to support the findings, particularly regarding quality as an outcome of organizational ways of working.

It came up that product quality issues are due to hundreds of different steps, not one single root cause. Also, the technical service doesn't have a budget to perform the RCA before the case becomes a PIP. An interesting suggestion for improvement was to have two different types of RCA. The other would focus more on determining the technical root cause and the other more on the process side, what made the issue possible to even happen in the first place. These RCA-related improvements are discussed more in the following chapters.

Table 12. Quotes from discussions that are not suitable for themes determined.

General quotes
<i>"Yeah, you know what happens on field is a sum up of hundreds of steps, even hundreds between hundreds and thousands of different step and choice is done in the full supply chain or management chain, everything, then it's a result of everything, not only of the work of RDE, for example. "</i> Interviewee 13
<i>"You can not solve an issue you can't see. "</i> Interviewee 13
<i>"It's quite common now that it says that this is how it's always been done before, and that's how it's done now because this is how it's always been done. "</i> Interviewee 14
<i>"An experienced technical service and technicians in field is really vital to get the proper RCA. "</i> Interviewee 2
<i>"But first I think the RCA itself should be done to find the root cause and then how we prevent it, we should also look at it from the process side, what went wrong. So our RCA is now performing differently than if we really want to improve everything. I would say that it's a bit like maybe missing. "</i> Interviewee 14

4.3.3 Root Cause Analysis

The root cause analysis was done based on the interviews. The interviewees talked about the root causes from their own perspective and referred in general terms, not to a specific subcategory. To be able to find the underlying root causes, an Ishikawa diagram and 5 whys were performed from the interview data. Both the Ishikawa diagram and 5 Whys were used to organize and visualize the root cause analysis.

The Ishikawa diagram is built on the problem definition “Product quality issues aren’t detected or prevented early” (Figure 11). This was the main theme and question in the interviews. For the Ishikawa diagram, the analyzed interview themes were used as branches. The analysis showed that the factors contributing to quality issues are distributed across those seven themes. Each branch contains more detailed challenges that were repeatedly mentioned by the interviewees. The Ishikawa shows how all the more detailed challenges are closely connected and are based on the same underlying root causes. Weaknesses in documentation have an impact on communication as well as communication issues affect the process execution. Issues in process execution reduce the effectiveness of quality control. Cultural and competence-related factors are affecting all branches.

The diagram does not only organize the underlying causes into a visual structure. It also demonstrates that the case company’s quality challenges are due to issues in collaboration, communication, documentation, interactions, and culture. Information gotten from the diagram’s analysis was used to guide the 5 Whys analysis.

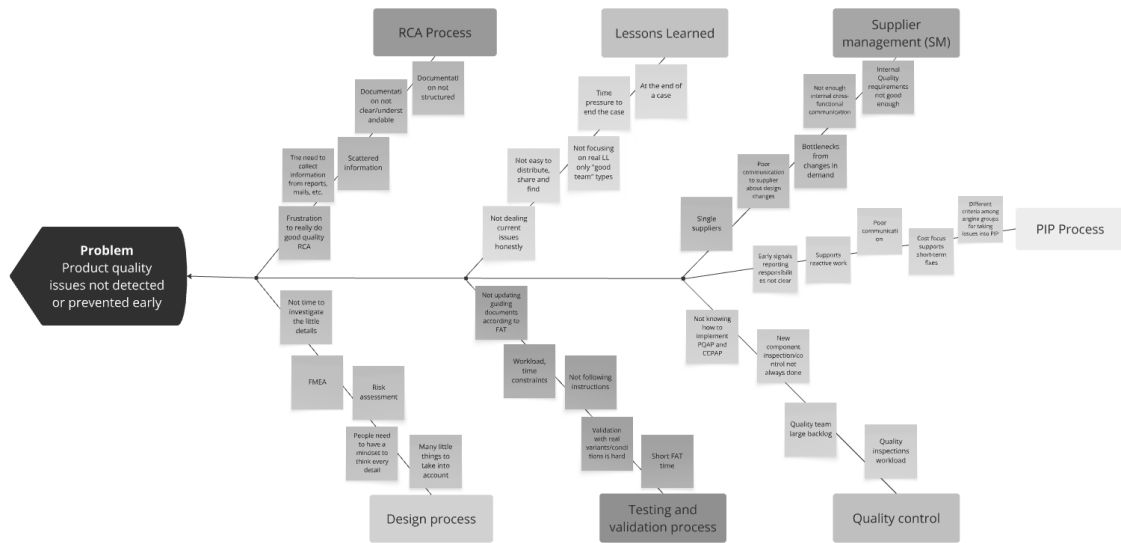


Figure 11. Ishikawa diagram.

The 5 whys analysis was conducted to deepen the Ishikawa diagrams provided analysis of the underlying root causes. This method was used for the branches RCA process, Supplier management and Design process, because those were the main themes discussed in the interviews. So the 5 whys analysis included three analyses of different topics. The problem definition from Ishikawa diagram was used as the first why, starting question.

The first 5 Whys was conducted on the theme Supplier Management (Figure 12). It revealed the underlying root cause of product quality issues related to supplier management. The defined root cause is "Introduction of practices isn't clear, and practices face reluctance and frustration, if those are needed to use." This analysis didn't take into account the supplier competence as the root cause, only focused on the internal view.

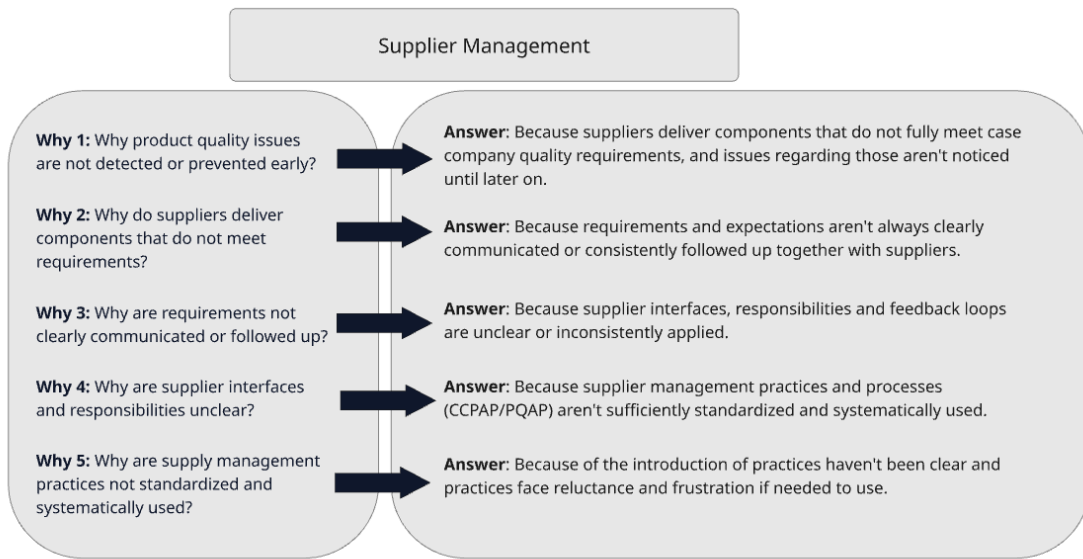


Figure 12. 5 Whys analysis of the Supplier Management.

The second 5 Whys was conducted to the RCA process theme (Figure 13). Investigating it, revealed an underlying root cause. The identified root cause is “RCA is treated as a reactive activity rather than a standardized, learning-oriented process that has a standardized document to fill. It is based on time constraints and enthusiasm, not by standardized required fields to fill.” The challenges do not lie in the absence of RCA, but in their inconsistency and shallow application. This was due to time pressure, workload and non-standardized requirements for RCA.

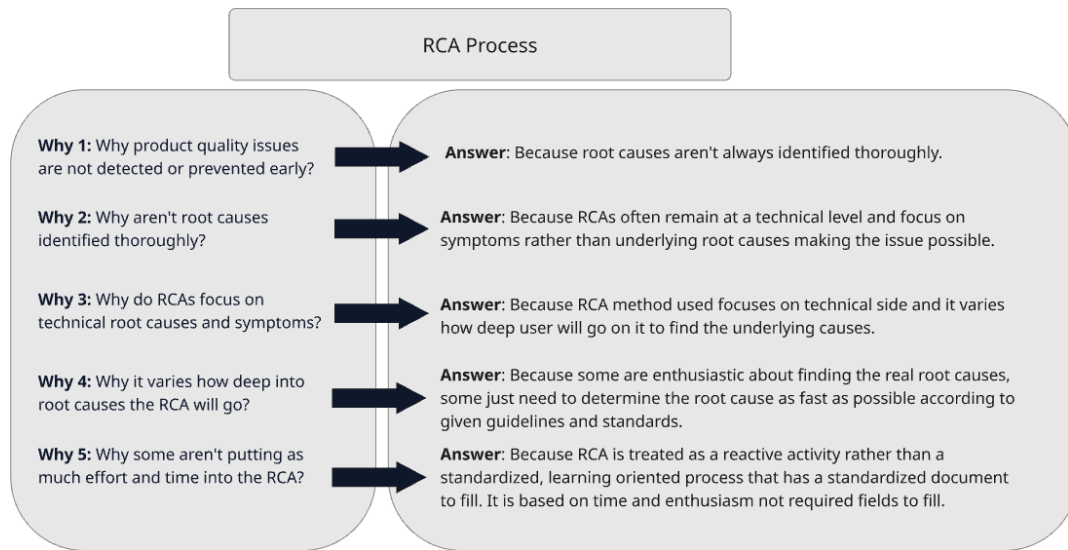


Figure 13. 5 Whys analysis of the RCA Process.

The third 5 Whys was conducted to the Design process theme (Figure 14). It revealed as a root cause to be “Quality expectations aren’t consistently translated into concrete design requirements and decision criteria.” This highlights that many issues originate from not updating the design decisions and requirements sufficiently. The quality risks are just introduced later on in the process.

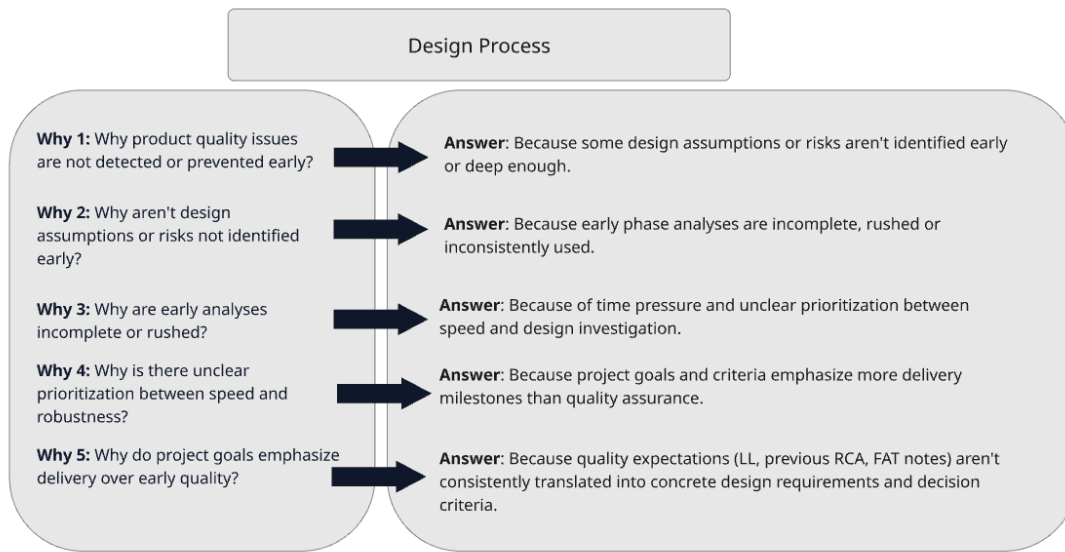


Figure 14. 5 Whys analysis of the Design Process.

As the 5 whys analysis progressed, it could be seen that the identified problem do not stem from a single failure or cause point. Moreover, it stems from multiple systemic weaknesses across processes, roles and the case company's interfaces. Although the 5 Whys were conducted on different themes, they consistently pointed to similar root causes. Underlying root causes regarding clarity of responsibility, early validation practices and structured documentation and reporting mechanisms. Also, combining the deeper analysis of the 5 Whys with the previously determined Ishikawa diagram, the findings about similarities across themes become stronger. In the Ishikawa, several more detailed causes were determined and between those, without boundaries, can be seen the same similarities that were defined from the 5 Whys analyses.

4.4 Improve phase

The improvement suggestions were based on what came up on the interviews as well as on the previously determined root causes (Figure 15). From quantification Table 10, can be seen that in three interviews the testing/validation/vibration measurements of the engines came up, but that is something that can't be done easily and it is a matter of physical limits as well as costs. That is not taken into account in this improve phase. Also,

the point is to focus on improvement actions that the case company can internally do. They can't change the supplier's processes, so only improvement suggestions regarding supplier that can be done internally in the case company are taken into account.



Figure 15. Visualization of finding the suggested improvement actions.

The improvement suggestions were grouped into three different themes according to the root causes determined earlier and the improvement themes gotten from the interviews (Figure 15). It was asked in the first meeting with the R&D management team, that this research should provide three actionable improvement suggestions to focus on. To be able to address these root causes, the improvement suggestion needs to counter the behavioral patterns, increase transparency, explain meaning behind actions and strengthen shared responsibility. By addressing the cultural and behavioral roots that sustain quality issues, it is possible to prevent them from occurring.

The first group focused on the theme of embracing, motivating and bringing possibilities for collaboration and information sharing. The first improvement suggestion is to establish an open, low effort, easy accessible and cross-functional quality forum with clearly defined ownership towards different subjects. This forum would be the place to discuss about early signals, small risks and recurring issues without blame or judgment. Also, this forum would be a place to discuss and share information with suppliers as well as internal supplier management concerns about CCPAP and PQAP processes. This way, the improvement suggestion would also encounter the improvement suggestion theme supplier quality that was brought up in the interviews.

The forum could be implemented as a structured Microsoft Teams group with dedicated channels for early signals and risks, recurring issues, supplier-related observations and lessons learned. Each channel would have a named responsible person to ensure follow-up and clarity of ownership. Anyone could be able to join the group and share the group with colleagues. The aim would be to get a cross-functional group of colleagues, especially the doer lever, to join and actively discuss in it. This approach would lower the threshold for raising quality concerns, supports cross-functional collaboration and help transform fragmented information into shared organizational learning.

The second group focuses on the improvement suggestion that can bring clarity and meaning to the reports, documents, instructions and guidelines. This improvement suggestion is addressing the systemic issues identified in the analyze phase about the RCA documentation. As this research was to find the underlying non-technical root causes, it would be an improvement suggestion to start providing two RCAs. One would focus on the technical root cause and the other would focus on analyzing the ways of working and processes on where the issue started from. This was brought up by one of the interviewees (Table 12).

The second improvement suggestion is to establish a mandatory standardized RCA documentation template. It would have key required sections which must be filled in, for example:

- The technical root cause(s): What technically failed in the product or component.
- The process-based non-technical root cause(s): Which organizational, ways of working, process, communication, documentation or competence-related factors allowed the technical issue to occur or remain undetected.

This template would need to be done to every issue occurred and provided in the same, clear form in Salesforce. Also, depending on both root causes, it would be a good improvement to set a mandatory category field to the issue. This way it would be possible to follow, what type of issues the case company has the most.

The third improvement suggestion focuses on the LL and learning from mistakes. In the interviews it came up that LL are commonly done in the end of the PIP not during the whole process. The third improvement suggestion is to shift LL from an end of project activity to a continuous learning process throughout the improvement project lifecycle. This would be an easy shift with for example these learning checkpoints during the project, and short reflections at key gates. This would improve the reflections, documentation quality and organizational learning by ensuring that insights are recorded while they are still fresh in mind and meaningful. For example, these LL during the project could be published to the previously mentioned Teams channel for LL. This would also help the updating of guidelines and instructions easier, because those could be done simultaneously and gradually, not everything at the same time. This point of view takes into account the improvement theme of clearer instructions and guidelines, which came up in the interviews.

These three improvement suggestions were selected because they all address multiple root causes simultaneously and take into account the interviewees' opinions on improvements. The focus is strongly on systemic and internally controllable factors rather than isolated technical fixes. The proposed improvements aim to strengthen the case company's system more than targeting something like "build a new testing factory". However, the following and controlling of these improvements will be tricky just because of them not being so straightforward.

4.5 Control phase

The control phase is going to answer the question that how we are making sure that these improvements continue to work after this research. The aim is that these improvements become the way of working in the case company. For the improvement activities, three controlling and monitoring ways were selected.

The cross-functional discussion forum would be controlled by the named channel owners. Their responsibility would be to follow the channels, conversations, and subjects discussed. Also, to motivate and embrace people to use the forum and to have open discussions. There could be a periodic review of number of raised early signals, the number of discussions leading to actions and the raised similarity of issues with different engine groups. But the aim of the forums control and monitoring is to achieve clear ownership and information sharing not formal reporting.

The control plan for the standardized RCA documentation would be to first introduce the RCA template, provide instructions and explanations on how to use it. Also, some implementation workshops could be used to integrate the use of the template. It would be important to follow the use of the categories. It could be controlled through mandatory fields in Salesforce so it wouldn't be possible to save without filling the category fields. RCA documentation and the use of the template could be controlled through periodic quality review of RCA documentation, more like taking samples not going through all. It would also be interesting to follow both RCA categories for example, as KPIs to monitor trends and to know where to improve more.

The third improvement, continuous lessons learned, control plan could be to monitor the LL captured during the project and the gate that those are documented. Also, to provide visibility and reuse of the LL, for example, in the cross-functional forum. Probably some kind of categorization of LL would be good to be able to make them easier to follow. Also, categorizing the LL regarding the subject they belong to, would make it easier to go through them when a similar project is started. The aim of the control should be to ensure that learning loops remain active even under time pressure and time passing.

Together, these control plans and mechanisms could support long-term prevention of quality issues. It was mentioned in the interviews that the focus should be more on the long-term fixes not short-term. These improvements and their control plans would support long-term fixes and reinforce the case company's learning.

5 Discussion

The purpose of this chapter is to discuss the main findings of this research and reflect on the research objectives and questions. In addition, the chapter reflects on the chosen methodology and tools used and discusses the scope of the research. This chapter aims to provide managerial implications, both company-specific and industry-specific, as well as theoretical implications that contribute to existing literature.

The empirical part of this research revealed improvement suggestions to the case company: continuous lessons learned, a collaboration forum and a standardized RCA template. Each of these improvements are connected to the approaches to addressing quality issues presented in the literature review, continuous improvement and Kaizen.

CI represents a proactive philosophy rather than a reactive to be able to enhance organizational processes before issues escalate (Lloyd, 2025; Team, 2025). Empirical study showed that the case company's processes and culture emphasize reactive work rather than proactive. Improvement suggestion regarding the lessons learned encourages the proactive work. It also incorporates and enhances a culture of continuous improvement into everyday work. By embedding CI into organizational culture and daily operations, it can strengthen case company's process efficiency, support operational excellence and maintain dynamic markets (Team, 2025). Including management as well as the whole organization to follow the LL improvements, case company is closer to achieving better quality through CI (Gutiérrez et al., 2016).

An improvement suggestion given to case company about providing a standardized RCA template is related to the idea of Kaizen. Standardized improvements is one of the core principles of Kaizen (Munro et al., 2022, p. 960-961). Kaizen emphasizes small incremental changes and aims to maintain the implemented improvements. The aim with RCA improvement is to improve efficiency, provide structure and reduce waste in the long-term. These are closely aligned with the goals of Kaizen (Furterer, 2021, p. 55-57).

Providing a forum for open cross-functional discussion and collaboration is enhancing the Kaizen mindset inside the case company. Successful implementation of Kaizen into the case company needs open, collaborative, and responsive culture enhancement (Furterer, 2021, p. 55-57). It was mentioned that these improvements are just suggestions and perhaps could be further developed and piloted before implementation. This fact is also connected to the Kaizen culture by reinforcing the iterative nature of Kaizen: planning, testing and standardizing before fully implementing (Munro et al., 2022, p. 972).

Similarly, industry-wide managerial implications produced by this research are leaning on Kaizen and CI. Same kind of standardization of documents, embracing collaboration and learning from mistakes, can be implemented in the marine industry. It was discussed that quality is and needs to be a part of everybody's own daily work and mindset. As a conclusion, it can be stated that for the overall marine industry, this study provided insights on the importance of continuous improvement and the implementation of Kaizen culture.

One critical thing to mention is the categorization logic that was stated to be missing and was identified as a research gap. In today's literature, there wasn't a marine industry-specific categorization logic mentioned. Previous studies showed that there were commonly used categories such as design, manufacturing and mislabeling or marketing (Hora et al., 2011; OpsNinja, Inc, 2025). The case company used a similar wide categorization such as design, supplier and manufacturing/internal operations. The empirical study showed that the wide categorization isn't enough to be able to really understand and find the most critical causes leading to issues. In this research, subcategorizing was done by expertise area. This provided the possibility to analyze the primary category deeper.

This study contributes to the theoretical understanding of quality management and CI by addressing identified gaps related to methodology, RCA and industry context. This research extends the theoretical application of the DMAIC methodology beyond its

traditionally dominant quantitative and manufacturing-focused context. Previous studies showed that DMAIC methodology was applied in improvement projects that heavily relied on quantitative data within the automotive and electronics industries (Gutiérrez et al., 2016; Imansuri et al., 2024; Sumasto et al., 2023). In contrast, this study demonstrates that DMAIC can also be effectively applied in a qualitative research setting, where quality issues are explored through interviews and thematic analysis. Consistent with Gutierrez et al. (2016), the findings suggest that DMAIC does not need to be strictly or linearly followed to provide value. Instead, DMAIC functions as a flexible structuring framework that supports systematic investigation of quality issues even when quantitative data alone is insufficient. This contributes to theory by expanding the conceptual scope of DMAIC toward more context-sensitive and socio-technical applications.

Secondly, the research addresses a gap in quality and root cause analysis literature related to the underrepresentation of human and organizational factors. As discussed in the literature review, product quality in an industrial context is not limited to technical product characteristics, but also encompasses process quality, managerial practices and human contributions (K. S. Bhat, 2009; Calantone & Knight, 2000; Naidu et al., 2006). While quantitative quality studies often focus on measurable defects and process deviations, this research demonstrates that many quality issues originate from systemic organizational conditions, such as unclear requirements, insufficient communication and limitations in learning mechanisms. This supports and extends earlier findings by Erdinc and Vayvay (2008) and Kolus et al. (2018), who identified human factors, work procedures, and training as dominant contributors to quality problems. By empirically highlighting these non-technical root causes through qualitative analysis, the study strengthens the socio-technical perspective on quality management and challenges purely technical interpretations of product quality issues.

Finally, this study extends quality management and continuous improvement theory by transferring established insights from the automotive and electronics industries to the marine engine industry. Previous research has shown that product quality is influenced

by design, manufacturing, marketing and human factors (K. S. Bhat, 2009; Calantone & Knight, 2000; Hora et al., 2011; Naidu et al., 2006; OpsNinja, Inc, 2025). However, empirical studies have predominantly focused on industries characterized by high production volumes and relatively standardized products. This research confirms that the same underlying mechanisms are also present in a low-volume, high-complexity and highly customized industrial context (Gutiérrez et al., 2016; Imansuri et al., 2024; Sumasto et al., 2023). By demonstrating the relevance of these theoretical concepts outside their traditional domains, this study supports the generalizability of quality management and continuous improvement theories across industrial sectors.

Lastly, reflection on the research questions and objectives is made. As a reminder, the research questions for this research were:

1. What are the common causes of quality issues in marine industry engine products?
2. What actions and practices can be adopted to minimize or prevent these engine product quality issues?

Regarding the first research question, the findings indicate that quality issues can't be attributed only to technical defects or manufacturing errors. While design, supplier-related factors, and internal manufacturing processes emerged as primary categories, the empirical analysis demonstrated that these categories alone are too broad to enable meaningful understanding of root causes. By subcategorizing quality issues according to expertise areas, this research revealed that many recurring problems originate from organizational and human factors, such as unclear requirements, insufficient cross-functional communication, limited knowledge transfer, and weaknesses in learning mechanisms. These findings are consistent with earlier studies highlighting the role of socio-technical factors in quality outcomes, while also extending this understanding to the marine engine industry context.

Regarding the second research questions, the study identified three key improvement areas: continuous lessons learned, a structured forum for cross-functional collaboration

and a standardized root cause analysis template. These practices address the identified root causes by strengthening organizational learning, enhancing communication across functional boundaries and improving the consistency and depth of problem-solving activities. Rather than proposing isolated corrective actions, the findings emphasize the importance of embedding these practices into daily work routines, in line with continuous improvement and Kaizen principles. The proposed actions are therefore not only corrective in nature but also preventive, supporting a shift from reactive to proactive quality management.

As a reflection of the research questions and the research's possibility to answer them, the research can be stated to be successful. This research provided common causes leading to product quality issues within the case company and reflected those industry-wide. This research's improvement suggestions were possible to reflect on industry-wide implications as well as theoretical implications.

6 Conclusions

The purpose of this research was to explore the underlying causes of product quality issues in marine engine products and to identify actions and practices that can be adopted to minimize or prevent such issues. The research was motivated by a gap in existing quality management literature, particularly regarding the limited attention given to organizational and human factors, as well as the lack of marine industry-specific empirical research.

The research was conducted as a mixed-methods explanatory sequential design case study within a marine engine manufacturing context. The DMAIC methodology was used as a structuring framework to guide the investigation, combining empirical data from semi-structured interviews with root cause analysis, Pareto analysis, and thematic analysis. This approach enabled systematic exploration of complex quality issues in a context where purely quantitative data was insufficient to capture underlying causes. The findings demonstrate that quality issues in marine engine products are rarely caused by isolated technical failures. Instead, they often originate from broader systemic conditions, including unclear requirements, fragmented communication, limitations in organizational learning and insufficiently standardized problem-solving practices. While traditional categorization of quality issues into areas such as design, manufacturing and supplier provides an initial overview, the study shows that deeper subcategorization is necessary to meaningfully understand and address recurring problems.

Three key improvement areas were identified: continuous lessons learned, a structured forum for cross-functional collaboration and a standardized root cause analysis template. Together, these practices support a shift from reactive to proactive quality management by strengthening learning mechanisms, improving communication across organizational boundaries and enhancing the consistency of root cause analysis. The findings emphasize that effective quality improvement requires not only technical corrective actions, but also cultural and organizational development aligned with continuous improvement and Kaizen principles. From a theoretical perspective, this study contributes to quality

management literature by extending the application of the DMAIC methodology to a qualitative research context and by reinforcing the importance of socio-technical perspectives on quality.

Beyond identifying specific root causes and improvement actions, the interview material revealed broader reflections on the nature of quality in the marine engine industry. Interviewees emphasized that product quality is not determined by a single decision, tool or function, but rather by the cumulative effect of numerous decisions made across the organization and supply chain. As one interviewee described, *“you know what happens on field is a sum up of hundreds of steps, even hundreds between hundreds and thousands of different steps”* (Interviewee 13). This highlights the inherent complexity of marine engine systems and reinforces the idea that quality issues cannot be fully understood or prevented through isolated technical fixes alone.

From a marine industry perspective, this insight is particularly important. The reliability of marine engines, and ultimately the ability of vessels to operate safely without unexpected failures, depends not only on detecting defects, but on how effectively organizations recognize weak signals, share knowledge and learn across functional boundaries. As one interviewee also acknowledged this fact, *“you can not solve an issue you can’t see”* (Interviewee 13). This illustrates that quality risks can’t always be eliminated in advance, but their impact could be reduced through proactive learning-oriented practices.

The findings further indicate that established ways of working play a significant role in allowing quality issues to persist over time. Interviewees pointed out that practices are often followed without being questioned simply because *“this is how it has always been done”* (Interviewee 14). This observation reinforces one of the key conclusions of this thesis: improving product quality in the marine engine industry requires embedding quality into everyday work practices, rather than relying solely on reactive analyses or compliance-driven procedures

In conclusion, this study highlights that sustainable quality improvement in the marine engine industry requires a holistic approach that integrates technical expertise with organizational learning, collaboration and structured problem-solving. By making organizational root causes visible and linking improvement actions to continuous improvement principles, the research provides both practical and theoretical insights that support more effective and proactive quality management.

6.1 Limitations and future research

This research was conducted as a single case study within one case company operating in the marine engine industry. The empirical data covered product improvement cases from the time period 2020–2025 and focused specifically on four-stroke engine products. While this approach enabled an in-depth understanding of the organizational context and quality-related challenges, the findings cannot be directly generalized to other organizations, industries or product types. Furthermore, the automation department within the case company were excluded from the analysis, limiting the applicability of the results to the full organizational scope.

The research design also imposed certain data-related limitations. The empirical analysis relied primarily on semi-structured interview data, consisting of seven interviews. Although the interviews provided rich qualitative insights, the limited number of participants restricts the breadth of perspectives captured. In addition, the quality and consistency of existing root cause analysis (RCA) documentation varied across cases, which may have influenced the accuracy of both the primary categorization and the subsequent subcategorization of quality issues.

Another limitation concerns the categorization logic applied in the analysis. Subcategorization of quality issues was conducted using a single perspective, expertise area. Due to time constraints and limitations in data quality, alternative categorization logics and multiple Pareto analyses were not applied. As a result, different analytical approaches

could potentially have led to different prioritization outcomes or highlighted additional critical root causes.

Finally, the literature review was limited to sources published in English and Finnish within the timeframe of 2000–2025. This may have excluded relevant studies published in other languages or earlier foundational quality management research. Based on these limitations, several avenues for future research can be identified. Future studies could increase the number of interviews and include facilitated cross-functional workshops to capture a wider range of perspectives and enable deeper collective root cause exploration. In addition, applying more formalized causal analysis tools, such as fault tree analysis, could complement or replace the 5 Whys method when addressing complex and interdependent quality issues.

Future research could also test alternative categorization logics and compare the outcomes of multiple Pareto analyses to further refine prioritization approaches in quality management. Finally, expanding the scope of analysis to include automation systems, additional engine types, or multiple case companies would support broader analytical generalizability and provide a more comprehensive understanding of quality issues across the marine industry and other complex industrial contexts.

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Appendices

Appendix 1. Project Charter

SIX SIGMA PROJECT CHARTER TEMPLATE

GENERAL PROJECT INFORMATION

PROJECT NAME	PROJECT MANAGER	PROJECT SPONSOR
Product Quality Issues	Iina Elorinne	Case Company
SUPERVISORS	EXPECTED START DATE	EXPECTED COMPLETION DATE
Jouni Juntunen (University of Vaasa) / Mikko Kekkonen (Case Company)	11/2025	4/2026

PROJECT OVERVIEW

PROBLEM OR ISSUE	Case Company receives many product defects and doesn't have ability to prevent or to overcome the issues.
PURPOSE OF PROJECT	Come up with improvement suggestions and preventive actions on how <u>the case</u> company could prevent and overcome <u>the product</u> issues.
EXPECTED DELIVERABLES	Process changes, Competence needs, Restructuring needs, Investment proposals

PROJECT SCOPE

WITHIN SCOPE	<ul style="list-style-type: none"> - All reported product defects with product improvement process in the time frame 2020-2025 in data source Salesforce - All active engine types in the case company - Max. 10 interviews to support data analysis
OUTSIDE OF SCOPE	<ul style="list-style-type: none"> - No Product improvement process phase specific research - Product improvement processes with incomplete data

TENTATIVE SCHEDULE

KEY MILESTONE	START (weeks)	FINISH (weeks)
Form Project Team / Preliminary Review / Scope	44	45
Finalize Project Plan / Charter / Kick Off	45	46
Define Phase	46	48
Measurement Phase	48	2
Analysis Phase	2	6
Improvement Phase	7	9
Control Phase	10	11
Project Summary Report and Close Out	12	14

RESOURCES

PROJECT TEAM	Thesis writer Iina Elorinne, University and company supervisors
SUPPORT RESOURCES	<ul style="list-style-type: none"> - Other employees in the case company - Company data - Other professors in University of Vaasa - Other relevant studies in the field

RISKS, CONSTRAINTS, AND ASSUMPTIONS

RISKS	<ul style="list-style-type: none">- Not enough data available or the data being too poor to analyse- Not getting enough support or actions from supporters to keep up with the schedule- Difficulties in scheduling interviews with key stakeholders- Other environmental/health related risks
CONSTRAINTS	<ul style="list-style-type: none">- Time limit- Restrictions on publishing sensitive company information
ASSUMPTIONS	<ul style="list-style-type: none">- Stakeholders will provide timely input and participate- Stable organisational environment so no major restructuring or policy changes will occur during the project- Academic and company supervisors will be available for guidance throughout the project

Appendix 2. Categorization key words

1. Manufacturing

"production", "manufacturing", "machining", "casting", "welding", "mistake in production", "manufacturing process", "machining defect", "manufacturing error", "assembly line", "supplier process", "material supplied", "core boxes in the casting mould", "sintered", "overlay crack", "lead in lining", "grinding", "surface pressure", "tolerance", "spot weld", "laser weld", "porosity", "burrs", "metal chips", "wrong material", "incorrect lining casting temperature", "incorrect yield and tensile strength", "WPAP not done", "flushing line", "bearing damages", "supplier changed process", "polishing", "deviation", "manual grinding", "machining tool", "machining mistake", "surface quality of threads", "corrosion pits", "overlay crack", "lead in lining", "grinding", "surface pressure", "tolerance", "spot weld", "laser weld", "porosity", "burrs", "metal chips", "wrong material", "incorrect lining casting temperature", "incorrect yield and tensile strength", "WPAP not done", "flushing line", "bearing damages", "supplier changed process", "polishing", "deviation", "manual grinding", "machining tool", "machining mistake", "surface quality of threads", "corrosion pits"

2. Design

"design", "poor design", "design mistake", "wrong dimension", "not adequate", "not suitable", "design requirements", "design guidelines", "design error", "design basis", "design not compatible", "design weakness", "design flaw", "wrong holder design", "wrong resilient stiffness", "wrong resilient mounts configuration", "not enough contact surface", "too weak spring pin", "material and material thickness", "too rigid", "fastening points misaligned", "dimension deviations", "wrong design", "not enough contact surface", "too weak", "design of shaft", "design of supplier", "design of the VIC/VEC body", "review the design", "design as main reason", "limited sealing capability", "castability", "design improvements", "design not compatible", "design weakness", "design flaw", "wrong design", "not enough contact surface", "too weak", "design of shaft", "design of supplier", "design of the VIC/VEC body", "review the design", "design as main reason", "limited sealing capability", "castability", "design improvements"

3. Assembly

"assembly", "assembly error", "manual stop fail", "screw not secure", "insufficient screw tightening force", "insufficient axial clearance", "excessive tightening torque", "wrong tightening torque", "incorrect assembly", "incorrect type glue", "assembly line", "assembly process", "assembly deviation", "assembly not according to drawing", "incorrect assembly of running gear", "assembly error", "assembly process", "assembly deviation", "assembly not according to drawing", "incorrect assembly of running gear"

4. Supplier

"supplier", "supplied", "material supplied", "supplier root cause", "communication with supplier", "delivered by supplier", "sub-supplier", "purchasing", "wrong delivery from supplier side", "supplier changed process", "supplier process", "supplier communication", "supplier error", "supplier deviation", "supplier batch", "supplier side", "supplier process", "supplier communication", "supplier error", "supplier deviation", "supplier batch", "supplier side"

5. Other

"[repair](#) drawings", "documentation", "administrative", "not needed", "case closed", "lesson learned", "not applicable", "not relevant", "not required", "not needed", "case closed", "lesson learned", "not applicable", "not relevant", "not required"

Appendix 3. Interview questions and structure

STRUCTURE OF THE INTERVIEWS (semi-structured, English)

1. OPENING

The goal is to discuss together what kinds of non-technical conditions and patterns tend to exist before issues escalate to PIP-level cases, based on your experience from improvement projects.

2. PARETO BACKGROUND

Based on a Pareto analysis of PIP non-conformity costs, three issue subcategories (expertise areas of the issue component) stand out as the most significant: fuel systems, cylinder head & valve, and engine structure & power.

All interviewees, including yourself, have worked in improvement projects related to at least one of these categories.

We will use these categories as examples and anchors, not to discuss technical details, but to understand non-technical patterns around how issues in these areas emerge and escalate

Questions:

Which of these categories are you most familiar with through your projects?

- I'll mainly ask you to reflect based on that category, but feel free to draw parallels to others.

3. ROLE

Questions:

Can you briefly describe your role in these improvement projects?

At what stage do you typically get involved?

What kind of information do you usually receive when an issue reaches you?

4. ISSUE ARRIVAL

Questions:

When [fuel system / cylinder head / engine structure]-related issues reach to you, what has typically already happened upstream?"

What is usually clear at that point and what is unclear or missing?

Are there common reasons why issues in this subcategory were not detected or resolved earlier?

Based on your experience, what kinds of early signals of the issue becoming an issue likely existed?

Where do those signals typically get lost: process, tools, responsibilities, priorities, etc.?

5. PATTERNS

Questions: process

Which process weaknesses do you most often encounter in projects related to this category?

Are there specific gates, reviews or handovers where issues in this category tend to slip through?

Where does the formal process differ from how work actually happens?

Questions: roles and responsibilities

In projects related to this category, where do you most often see unclear ownership/responsibilities?

Which interfaces between teams or functions tend to cause problems upstream?

Are responsibilities ever assumed rather than explicitly defined?

Questions: information, documentation and feedback

What information is most often missing when issues in this category reach your project?

Which documentation or feedback would have helped prevent escalation?

How well does feedback from later stages reach earlier phases, in your experience?

Questions: priorities, pressures and trade-offs

What kinds of priorities or pressures upstream most often contribute to issues in this category?

Do you see recurring trade-offs being made (e.g. schedule vs. robustness)?

Do you see that there is problems regarding the supplier side or in the processes where supplier is included/reviewed/etc.?

6. RECURRENCE, COST AND PARETO REFLECTION

Questions:

These categories stand out as the most costly in Pareto analysis. From your perspective, why do issues in this category become so expensive once they reach this stage?

Which non-technical issues do you see recurring across different cases in this category?

What makes these issues difficult to eliminate permanently?

7. PREVENTION AND IMPROVEMENT

Questions:

From your perspective, what non-technical changes would most help prevent issues in this category from escalating to PIP-level cases?

Are these improvements subcategory-specific or more system-wide?

8. CLOSING REFLECTION

Questions:

If you could change one non-technical thing in how these issues are handled upstream, what would it be?

Is there something important related to this topic that we haven't discussed?

Are there colleagues that comes to your mind that could be relevant to interview regarding this subject?