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Reducing Repair Lead Times at NTS Hengelo

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Preface

Dear reader,

You are about to read my thesis, *“Reducing Repair Lead Times at NTS Hengelo.”* This research was conducted as part of the requirements for completing the bachelor’s program in Industrial Engineering and Management at the University of Twente, in collaboration with NTS Hengelo.

The study investigates the repair process flow at NTS Hengelo, aiming to solve a concrete operational problem while raising awareness about the strategic importance of the repair business. This area often receives less attention than it deserves. Throughout this research, I gained valuable experience applying the knowledge acquired during my studies in a real-world context.

Before delving into the research itself, I would like to express my sincere gratitude to those who supported me throughout this journey.

First, I would like to thank my University of Twente supervisors, Dr. Hao Chen and Dr. Yazan Devrim. Your consistent guidance, critical feedback, and unwavering support were instrumental in shaping this thesis, and I am deeply grateful for your mentorship.

I also extend my appreciation to my company supervisor, Dr. Bram Verhaagen. Your practical insights, willingness to support me whenever needed, and the time you invested in this project made a significant impact and helped steer my research in the right direction.

To all the employees at NTS Hengelo, thank you for your kindness and warm welcome. Your openness and support created a positive working environment and made my time at the company both productive and enjoyable.

Lastly, I want to express my heartfelt thanks to my family and friends. Your patience, encouragement, and continuous support have been my foundation throughout this process. I truly could not have done it without you.

I hope you enjoy reading this thesis.

Mohamed Elshenawy
University of Twente
July 3rd, 2025

Management Summary

NTS Hengelo, part of the NTS Group, operates in the high-tech manufacturing sector, delivering specialized low-volume, high-complexity systems and services to its main client, Company X. In recent years, Company X has faced increasing sustainability pressures from its own customers. In response, it has increasingly emphasized circularity by shifting focus toward repair, reuse, and lifecycle extension of components. These expectations have extended to NTS Hengelo, emphasizing the need to enhance sustainability practices by improving the speed and reliability of repair workflows. This shift underscored the urgency of improving lead time performance for active, recurring items, not only to meet contractual KPIs but also to strengthen NTS Hengelo's position and secure increased repair volumes in the future.

At the center of this challenge lies the Repair Order Lead Time (ROLT) KPI, which requires 90% of repair orders to be completed within 51 calendar days. By the end of 2024, NTS Hengelo averaged only 80.3%**,** prompting this research into operational inefficiencies. The core research question guiding the study was:

"How can NTS Hengelo consistently achieve and sustain 90% from an 80.3% on-time repair order completion by identifying and reducing recurring bottlenecks in the repair process?"

The research followed the Managerial Problem-Solving Method (MPSM) and employed both qualitative and quantitative techniques. A comprehensive process overview was developed through BPMN modeling and stakeholder interviews. The study applied Pareto Analysis and ERP/Excel-based Process Mining to identify the key bottlenecks, enabling both item-level and step-level diagnosis of delays across all 2024 repair data.

The analysis revealed six recurring repair items that contributed disproportionately to missed ROLT targets:

1. ALPHA V2
2. BRAVO V1
3. BRAVO V2
4. CHARLIE
5. BRAVO V3
6. DELTA

These items were then examined across the seven standardized repair steps. It was found that three steps, Cleanroom Analysis, Logistics & Planning, and Cleanroom Execution, accounted for 87% of total unproductive time in these repairs.

Four main root causes were identified:

- Repeated quotation approvals due to inconsistent pricing,
- Missing or inconsistent ERP logging,
- Low awareness of repair urgency among internal stakeholders,
- Weak task prioritization and scheduling in the cleanroom.

The study proposed a fixed-cost pricing model to address these issues, supported by a categorization flowchart based on the Bill of Materials. This model was chosen due to its practicality, ease of implementation, and proven effectiveness within NTS Hengelo. The item ALPHA V1 which had already undergone a fixed-pricing transformation, served as a compelling internal success case.

The average repair duration for that item dropped from 61.5 days to just 12.5 days, and ROLT compliance rose from 55% to 94%. These outcomes demonstrated the tangible benefits of eliminating repeated quotation approvals and standardizing administrative workflows.

This approach segments repair orders by cost structure and historical consistency, allowing NTS Hengelo to pre-approve pricing for recurring items and eliminate redundant administrative approvals. The flowchart also serves as a continuous tool to flag future items eligible for fixed pricing.

While fixed pricing addresses the core administrative inefficiencies, additional measures are required to achieve and sustain 90% ROLT compliance. These include:

- Enforcing ERP logging to enable reliable performance tracking,
- Raising stakeholder awareness of the repair process's strategic importance,
- Introducing cleanroom dashboards to enhance visibility and scheduling discipline.

Together, these interventions provide an actionable, phased roadmap. While this research solves a critical operational issue, it also aims to raise awareness of the broader strategic value of repairs at NTS Hengelo. Strengthening repair performance is a step toward building a stronger business case for higher repair intake and supplier rating improvement**.**

This thesis contributes to practice by offering a structured, scalable improvement plan tailored to NTS Hengelo’s environment. It contributes to theory by extending Lean Thinking, Business Process Standardization (BPS), and Business Process Reengineering (BPR) into the service-heavy context of high-mix, low-volume repair operations. Ultimately, the research bridges theory and practice to deliver measurable improvements in lead time, coordination, and process reliability.

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List of Abbreviations

KPIs:	Key Performance Indicators
ROLT:	Repair Order Lead Time
ROs:	Repair Orders
CTO:	Chief Technology Officer
OTIF:	On Time & In Full
TBD:	Technical Build Document
DN:	Deviation Note
BPMN:	Business Process Model and Notation
RCA:	Root Cause Analysis
WIP:	Work In Progress
VSM:	Value Stream Mapping
MCDM:	Multi-Criteria Decision Making
DMAIC:	Define, Measure, Analyze, Improve, Control
ERP:	Enterprise Resource Planning system
BPS:	Business Process Standardization
BPR:	Business Process Reengineering
BoM:	Bill of Materials
CV:	Coefficient of Variation

1. Introduction

The first chapter introduces the research project and its context within the operations of NTS Hengelo. It begins by outlining the company background and industry developments, followed by the core problems, research goals, scope, and guiding methodology. Together, these sections provide the foundation for the research and clarify its relevance and approach.

1.1. Company Description

NTS-Group, headquartered in Eindhoven, Netherlands, is one of the leading international manufacturers in the semiconductor and analytical market. With 12 sites operating in the Netherlands, Czech Republic, United States, Singapore, and China, the company specializes in high-precision manufacturing. Over its 75 years of experience, NTS-Group has 1,800 professionals working hand in hand and generates 412 million euros in revenue, solidifying its position as a first-tier contract manufacturer (NTS, 2025).

The semiconductor market is evolving at a rapid rate after a dip in 2023 due to a combination of several factors, such as rising inflation, geopolitical unrest, and the remaining effects of the COVID-19 pandemic (Barnhill, 2024). However, it has increased by 18.1%, accumulating 626 billion dollars in 2024 (Gartner, 2025). As shown in Figure 1.1, the semiconductor market is forecasted to reach 1 trillion dollars by 2030, growing more than twice as quickly as the global GDP (PwC, 2024). Given its trajectory, NTS-Group has been and continues to capitalize on this curve by bringing years of expertise and providing the semiconductor and analytical industries with unique and fitting solutions.

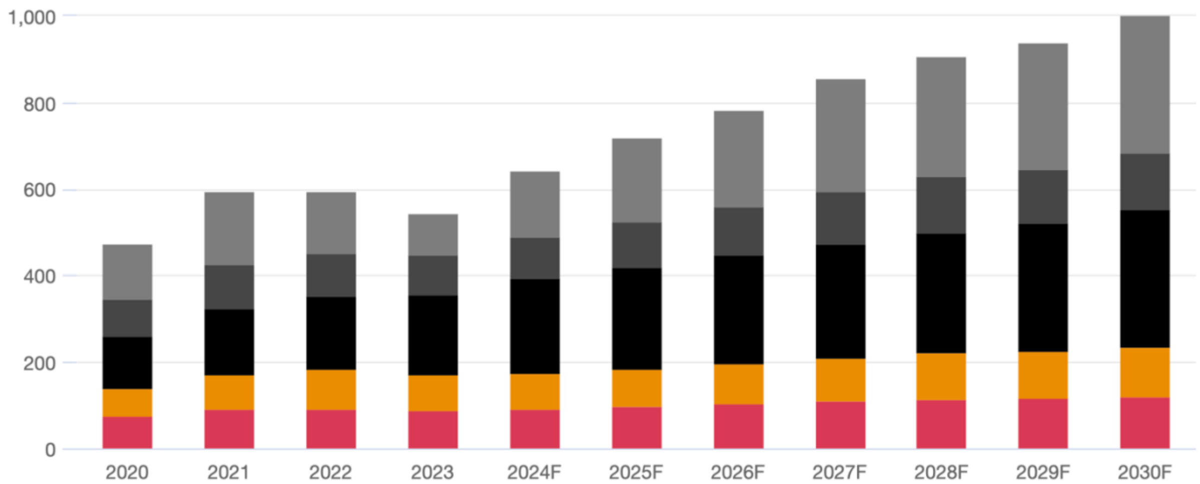

Figure 1.1: Global semiconductor market forecast (2020–2030). Adapted from PwC (2024).

As markets expand and technology advances, the discussion around sustainability is becoming increasingly prominent. Companies are starting to realize the hidden value in the materials in the end-of-life stage (Contec, n.d.). As a result, companies are starting to integrate circular and sustainable principles into their operations, such as extending product lifecycles and reusing/recovering materials or components of products into their operations. Not only is the shift environmentally positive but also financially attractive. In 2023, the global circular economy market was valued at USD 553 billion and is projected to grow at a compound annual growth rate of 13.19% by 2030 (Contec, n.d.). Moreover, research shows that utilizing non-virgin materials or components can achieve significant cost savings estimated at 700 billion dollars annually (Contec, n.d.). In high-precision manufacturing, circularity can be perceived as both a challenge and an opportunity since materials and production costs are significant. Given this trend, exploring strategies to improve circularity is gaining momentum within the industries in which NTS-Group operates.

As part of NTS-Group's comprehensive approach, it ensures efficient supply chain management by combining advanced technical capabilities with cost-effective manufacturability. This thesis will focus specifically on NTS Hengelo, one of NTS Group's key sites specializing in ultra-precision manufacturing.

NTS Hengelo is known for its expertise in manufacturing ultra-precise components that are accurate up to one-millionth of a meter. Moreover, their facility features a 1600 m^2 cleanroom utilized for mechatronic assemblies and a 5000 m^2 production space allowing for large-scale, high-precision manufacturing (NTS, 2025).

1.2. Problem Description

This section outlines the specific problems driving this research. It begins with a contextual explanation of market and customer expectations, followed by a clearly defined action problem and the underlying core problem. This structure ensures a logical transition from broad external pressures to internal operational challenges at NTS Hengelo.

1.2.1. Problem Context

As stated in the previous section, the adoption of sustainability practices is gaining increased attention across industries. Company X is NTS Hengelo’s main customer, accounting for approximately 80% of its revenue, as visualized in Figure 1.2, and is facing growing sustainability demands from its own customers. These customers expect Company X to integrate products and components back into the supply chain and will offer in return financial incentives for achieving circularity targets.

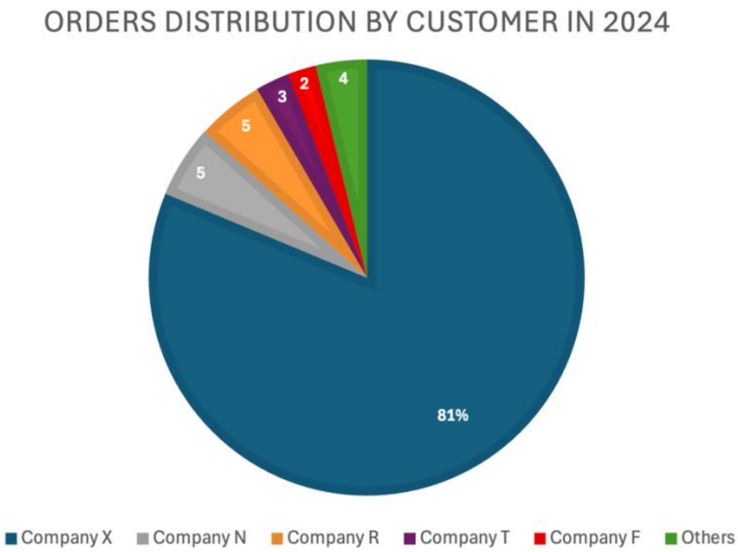

Figure 1.2: Distribution of NTS Hengelo Orders by Customer in 2024

To align with these expectations, Company X has extended this sustainability pressure to its suppliers, including NTS Hengelo, urging them to improve repair and reuse processes. To ensure compliance, Company X has introduced a set of Key Performance Indicators (KPIs) that NTS Hengelo must adhere to, and their performance will be measured on a monthly basis**.**

The two relevant KPIs are:

1. **Repair Order Lead Time (ROLT) Compliance:** Measures whether the supplier repairs and delivers products within the expected timeframe:
    - Acceptable: 90% or higher compliance
    - Intermediate: 81 -90 % compliance
    - Unacceptable: 80% or lower compliance

2. **Supplier Repair Rate:** Assesses repair performance based on deviation from expected values:
    - Acceptable: ≤10% deviation
    - Intermediate: Slightly above 10% deviation
    - Unacceptable: >10% deviation

Even though both KPIs are relevant for supplier performance assessment, this research will solely focus on the first KPI, **Repair Lead Time Compliance.** The Supplier Repair Rate KPI will **not** be the focus because NTS Hengelo consistently scores above target, thus already exceeding expectations. This indicates that the technical repair capabilities are not the issue, and the primary challenge lies in meeting the repair lead time KPI since it is lower than expectations. As a result, this research will limit its focus to identifying and addressing the factors contributing to these delays. This will be further expanded on in the following sections.

1.2.2. Action Problem

In the beginning, the main issue NTS Hengelo wanted to address was the lack of a defined strategy regarding circularity in handling returned products. However, this approach was deemed too broad, thus leading to a shift to find and tackle targeted and operational bottlenecks. The analysis of key performance indicators (KPIs) showed that the supplier success repair rate KPI (stated in the previous section) exceeded expectations with a 99.5% repair rate. However, the repair lead time compliance KPI scored lower at 80.3%, consistently falling short of the 90% target. This discrepancy highlights a critical issue, thus making it the main focus of this thesis.

According to Heerkens & Van Winden (2021, p.22), this updated problem aligns well with the definition of an action problem, which is a discrepancy perceived by the problem owner between the norm and the reality. For NTS Hengelo (the problem owner), the norm is consistently completing **90%** of repair returns to Company X within the agreed timeframe. However, the reality is that on average only **80.3%** are completed on time. This formulated action problem in Figure 1.3, highlighted in yellow, serves as a foundation for the creation of a detailed analysis that pinpoints the root problems causing these delays through the use of a problem cluster.

1.2.3. Core Problem

As shown in Figure 1.3, NTS Hengelo faces one core problem that hinders its ability to meet the action problem. This core problem, highlighted in blue, is that the **Current repair process bottlenecks are not identified.**

The core problem aligned well with the criteria outlined by Heerkens & Van Winden (2017, p. 44), where in these criteria they emphasize:

- **Feasibility:** The problem should be solvable within the available resources and timeframe.
- **Impact:** The selected issue should contribute significantly to resolving the action problem.
- **Controllability:** The organization should have direct influence over the core problem.

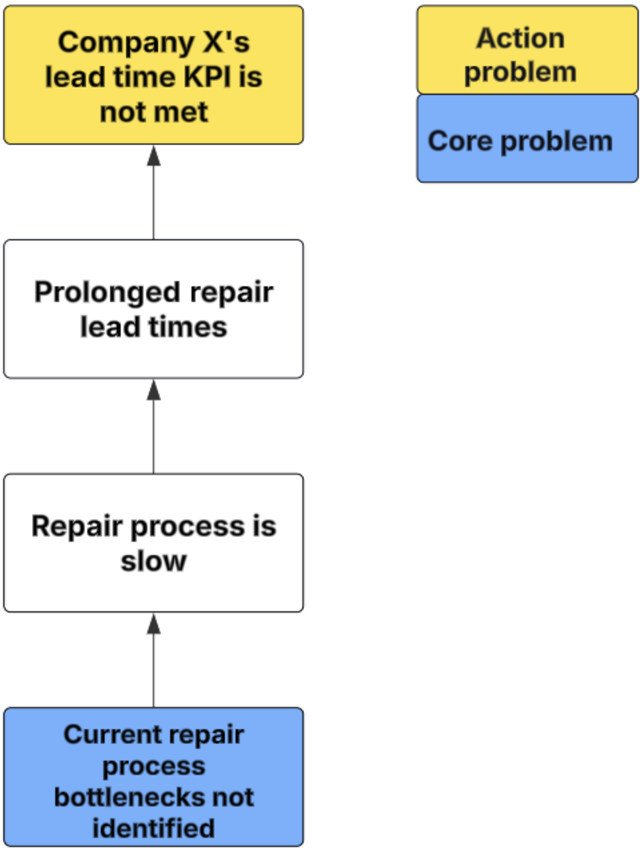

Figure 1.3: Problem Cluster

The following provides an explanation of the core problem and rationale for selecting it as the primary focus of this research.

After following the problem cluster analysis, it was revealed that the problems in the repair process originate from a lack of knowledge about the current bottlenecks in the repair process. This absence of knowledge makes it difficult to pinpoint specific inefficiencies and meet targets.

It is also important to consider key contextual elements that have contributed to the emergence of this issue. One such factor is the recent introduction of formal KPIs regarding repairs. The repair lead time KPI was only officially introduced in early 2025, meaning that NTS Hengelo is still in the early stages of adapting to this performance requirement. This research will support NTS Hengelo by identifying and addressing the main bottlenecks to align effectively with the new expectations.

As a consequence of not identifying these bottlenecks**,** a critical operational challenge has emerged**.** The repair process is slow, meaning that the repairs follow inconsistent workflows. That leads to bottlenecks continuing to persist and delay completion times.

Since these problems stem from process inefficiencies, they are directly solvable within the scope of this research. This core problem is chosen because it offers a realistic and actionable pathway to improving repair efficiency. Addressing this issue will directly solve the action problem.

1.3. Research Approach

In this section, the research approach outlines the framework to identify and address the bottleneck(s). It begins by defining the scope and limitations of the study, followed by the research goal, methodology, main research question, and guiding sub-research questions. The chapter concludes with a reflection on reliability and validity to ensure methodological rigor.

1.3.1. Scope and Limitations

This research focuses specifically on repair process data from the year 2024. This scope is defined by both temporal and methodological limitations that shape the feasibility and validity of the analysis.

From a temporal perspective, the decision to use 2024 as the primary data year is based on two key considerations. First, the repair process at NTS Hengelo was only formally established in 2023. However, the data from that year is incomplete and inconsistent due to the initial implementation phase thus making it unsuitable for comprehensive analysis. Second, only a few months of data from 2025 are available. These months may not reflect a steady operational state. As a result, 2024 offers the most complete, recent, and stable dataset for understanding standard repair process performance thus enabling a more reliable and representative analysis.

The scope of the research is further refined by focusing only on repairs linked to a single customer, Company X. This decision is justified by the fact that approximately 79% of all repairs at NTS Hengelo are associated with this customer, visualized in Figure 1.4. Moreover, Company X is the one evaluating supplier performance based on the newly introduced repair-related KPIs. The research aligns with the dominant operational impact and the stakeholder responsible for KPI compliance by limiting the analysis to Company X. Even though the analysis mainly focuses on repair orders completed in 2024, repair orders that were initiated in late 2023 or finalized in early 2025 are included in specific cases. This approach ensures the inclusion of full repair cycles, avoiding skewed insights caused by evaluating partially processed orders.

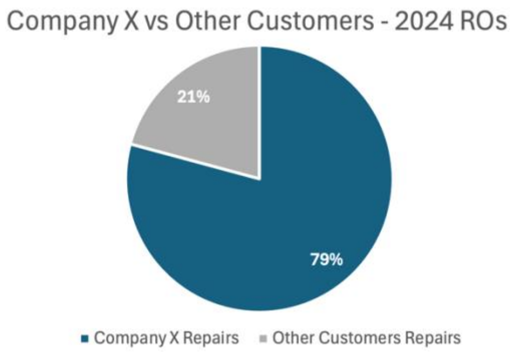

Figure 1.4: Share of Company X Repairs vs Other Customers at NTS Hengelo in 2024

From a methodological perspective, the research faces limitations related to the thesis timeframe and scope of analysis. Due to the 10-week duration of this thesis, the research concentrates on identifying and reducing the main bottlenecks that hinder timely repair completion. It does not address every possible inefficiency in the process. The short timeframe of 10 weeks also limits the ability to implement and measure the real-world impact of the proposed solutions. While the research aims to provide actionable and evidence-based recommendations, their long-term effectiveness cannot be directly validated within the project's duration. Implementation and post-implementation performance tracking depend on follow-up by NTS Hengelo and are therefore beyond the control of the thesis.

Additionally, confidentiality constraints pose a limitation on the level of detail accessible in the operational data. While detailed step-level labor hour allocations are available for certain analyses, in some cases, this information is restricted due to internal confidentiality policies.

These cases are clearly highlighted in the analysis. A reverse engineering approach is employed to address this limitation, using company-provided logic to estimate the total labor hours per repair order. This ensures that the analysis remains robust, methodologically sound, and aligned with organizational confidentiality guidelines.

Despite these limitations, the chosen scope allows for a focused and practical investigation into the repair process and its current inefficiencies. The findings generated through this research will lay the groundwork for further monitoring and improvement efforts at NTS Hengelo. As a result, it will support long-term alignment with Company X's performance expectations.

1.3.2. Research Goal

This research addresses the core problem identified in Figure 1.3: **the current repair process bottlenecks at NTS Hengelo are not identified**. This issue prevents the organization from consistently meeting the 90% on-time repair lead time target set by Company X. The existing performance level of 80.3% highlights a gap between expectations and actual outcomes.

The goal is to systematically identify and analyze the bottlenecks that cause delays in the repair process and to develop feasible, evidence-based solutions that improve on-time delivery performance. By solving this core problem, the research directly contributes to resolving the broader action problem: NTS Hengelo's inability to consistently meet the lead time compliance KPI. The intended outcomes: (1) A clear diagnosis of the most critical bottlenecks in the repair process, (2) Tailored improvement actions based on qualitative and quantitative insights, and (3) Practical recommendations that support sustainable performance improvements. All findings and deliverables are designed to fit within the scope and timeline of the 10-week thesis assignment.

1.3.3. Research Methodology

This research applies the **Managerial Problem-Solving Method (MPSM)** as the guiding framework. Several methodologies were considered, including CRISP-DM, which is highly data-driven (Schröer et al., 2021). However, since this study relies not only on quantitative data but also on stakeholder insights and organizational context, MPSM offers a more balanced and practical approach. It provides a clear, structured path for identifying and solving the core problem while ensuring that the proposed solutions are feasible, tailored, and actionable (Heerkens & Van Winden, 2021).

Figure 1.5: MPSM Framework

The overall MPSM cycle followed in this research is illustrated above in Figure 1.5. The MPSM consists of seven consecutive steps, each contributing to a logical progression from problem identification to solution evaluation. Each sub-research question in this thesis aligns with one or more of these steps, ensuring consistency and coherence between the research design (visualized in Table 9.1) and its execution. The steps are applied as follows:

1. **Problem Identification**:
   This step defines the problem context, NTS Hengelo's failure to consistently meet the 90% repair lead time KPI, and identifies its root causes using a problem cluster analysis. This analysis is touched upon in **Section 1.2** and expanded on more in **Chapter 2.**
2. **Problem Approach**:
   In this MPSM step, the research goal and methodology are defined. Additionally, the feasibility and limitations are assessed based on available time and resources. The research questions are formulated and structured to guide the research. This is reflected in **Section 1.3**
3. **Problem Analysis**:
   The current repair process is analyzed to identify the bottlenecks. Quantitative and qualitative data are analyzed to identify inefficiencies. This analysis takes place in **Chapters 3 & 4**.
4. **Solution Generation:**
   A literature review and stakeholder input are used to identify possible bottlenecks and generate potential improvements. This step appears in **Sections 3.1. and 5.1.**
5. **Decision Making**:
   Alternative solutions are evaluated using selection criteria such as feasibility, impact, and efficiency. The most viable solutions are selected for implementation. This is detailed in **Sections 3.2., 5.2., and 5.3**.
6. **Implementation**:
   An actionable plan is proposed to address the identified bottlenecks, along with practical recommendations to improve the workflow. This part continues in **Chapter 6**.
7. **Evaluation**:
   The expected impact of the proposed solutions is assessed, including any remaining changes required to reach the target KPI. This is presented in **Chapter 6**.

By following the MPSM framework, this research ensures a structured, rigorous, and practical approach to tackling the core issue of unidentified bottlenecks in NTS Hengelo's repair process. Each main section of the thesis reflects the logical flow of the MPSM.

1.3.4. Research Question

Based on the research goals and organizational context, the following research question was constructed to systematically address the action and core problems identified in this study while using the MPSM as a guiding framework.

"How can NTS Hengelo consistently achieve and sustain 90% from an 80.3% on-time repair order completion by identifying and reducing recurring bottlenecks in the repair process?"

The main research question will be addressed through steps 1-6 of the MPSM, thus leading to a structured solution. Its effectiveness and relevance will be evaluated in Step 7 to make sure that the proposed improvements align with NTS Hengelo's repair efficiency goals.

1.3.5. Sub-research Questions

The main research question has been divided into several core and supporting sub-research questions to systematically answer it in a manageable way. These questions decompose the core problem into specific focus areas that will be explored in the following chapters. Each sub-question contributes to a deeper understanding of the repair process and informs the development of effective improvement strategies.

1. What KPIs, set by Company X, are currently used to evaluate the repair process at NTS Hengelo? *(Answered in **Section 1.2** and expanded on more in **Chapter 2**)*

Understanding the current KPIs and performance expectations is essential for framing the repair efficiency issue. This information is derived from interviews with relevant departments at NTS Hengelo and representatives of Company X. Additionally, supplier performance documentation shared by Company X in early 2025.

2. What does the current repair process flow at NTS Hengelo entail?
2.1. How are different types of repairs categorized and handled within this workflow at NTS Hengelo?

A clear understanding of the existing repair process and its variations is critical for bottleneck identification. Insights are gathered through interviews with stakeholders such as cleanroom workers, planners, the repair coordinator, and sales staff. These insights help map out the current state and distinguish between different types of repair orders. The explanation is presented in **Section 2.3.**

3. What are the major bottlenecks in NTS Hengelo's repair process*? (Answered in **Chapter 4**)*
*3.1. What structured methods can be used to identify process bottlenecks aimed at improving the repair process performance at NTS Hengelo? (Identified in **Sections 3.1** and **3.2**)*
*3.2. Which of these bottleneck identification methods are suitable for application to NTS Hengelo's repair process? (Chosen in **Section 3.3**)*

A literature review is conducted to identify established methods for bottleneck detection. These methods are assessed based on their conceptual foundations, applications in prior studies, practical relevance, and applicability to the repair process at NTS Hengelo. The goal is to identify one or more suitable methods for accurately detecting bottlenecks.

4. What are the solutions to address the identified bottlenecks in NTS Hengelo's repair process? *(Answered in **Chapter 5**)*
*4.1. What structured methods can be utilized to resolve bottlenecks and improve the operational performance of NTS Hengelo? (Identified in **Section 5.1**)*
*4.2. Which of these resolution methods are most applicable to the context of NTS Hengelo's repair process? (Chosen in **Section 5.4 & 5.5**)*

After identifying the key bottlenecks, various literature-based methods for resolving such process inefficiencies are explored. These methods are evaluated using similar criteria to those in core sub-question 3, aiming to select the most applicable and effective improvement approaches for NTS Hengelo.

5. What impact is expected from resolving the identified bottlenecks on NTS Hengelo's Repair Order Lead Time (ROLT) performance? *(Identified in **Chapter 6**)*
5.1. What additional process or system changes are necessary to help NTS Hengelo consistently achieve the 90% ROLT compliance target?

This sub-question focuses on evaluating the potential effects of the proposed solutions and identifying any external or internal factors that may influence the success of the interventions. This analysis helps develop both short-term and long-term recommendations to support NTS Hengelo in meeting its performance goals.

6. What tailored, evidence-based recommendations can be made to NTS Hengelo based on the findings from this research? *(Presented in **Chapter 6**)*

This final sub-question synthesizes all insights gained throughout the research to offer actionable and data-driven recommendations. These recommendations are grounded in both literature and empirical evidence. The aim of the recommendations is to help NTS Hengelo consistently meet its ROLT KPI and improve overall repair process efficiency.

1.3.6. Reliability and Validity

Validity ensures that the research accurately measures what it originally intended to measure (Cooper & Schindler, 2003). A triangulation approach is applied to ensure the validity of the research. This approach combines various data sources such as internal company reports, structured interviews, and process documentation (Mays & Pope, 2000). This allows for cross-verification of key observations and enhances confidence in the accuracy of the identified bottlenecks and proposed improvements. Furthermore, the alignment between the research objectives, sub-research questions, and the chosen methodology supports construct validity by ensuring that the research remains focused on addressing the core problem.

On the other hand, reliability measures how consistent and repeatable the research findings would be if the study were to be conducted again in similar conditions (Cooper & Schindler, 2003). To ensure the research is reliable, structured interviews and standardized data collection are integrated to minimize inconsistencies and bias. In addition, there is a clear documentation of the method(s) used to identify and address bottlenecks. Thus, making it possible for future researchers or practitioners to replicate the study under similar conditions.

However, some validity or reliability limitations may still exist within the research. For example, there is a possibility of interview bias or subjectivity during the interpretation of qualitative data, particularly in cases where responses are based on personal experiences or perceptions. Additionally, the available repair data may not fully reflect actual operational performance due to occasional delays by NTS Hengelo employees in data recording or incomplete entries. Certain process assumptions which in some cases are derived from limited observations or self-reported practices, may also influence the analysis. Moreover, variations or inconsistencies in documentation between departments could affect the completeness of the process mapping. These limitations are acknowledged and are critically reflected upon in the interpretation of results to maintain transparency and strengthen the trustworthiness of the conclusions drawn.

2. Current Repair Process Flow

This chapter provides a foundational understanding of NTS Hengelo's current repair operations and the key performance criteria used to evaluate them. It begins by examining the broader repair activity within NTS Hengelo and the sustainability-related KPIs introduced by Company X to assess supplier compliance. The chapter directly addresses core sub-research question 1: *"What KPIs, set by Company X, are currently used to evaluate the repair process at NTS Hengelo?"*

Sections 2.1 and **2.2** collectively explore the strategic importance of repairs. Moreover, they expand on the ROLT and Supplier Repair Rate KPIs, previously touched upon in **Section 1.2**. Both sections explain the measurement of the KPIs and the rationale behind focusing specifically on ROLT compliance. **Section 2.3** then shifts focus to the operational domain, addressing core sub-research question 2: *"What does the current repair process flow at NTS Hengelo entail?"* and its supporting sub-question 2.1: *"How are different types of repairs categorized and handled within this workflow at NTS Hengelo?"*

These sections provide the necessary context for analyzing internal repair process inefficiencies. By establishing how performance is measured and how repair orders are managed across different classifications, this chapter lays the groundwork for the bottleneck identification and analysis presented in Chapters 3 and 4.

2.1. Overview of Repair Activity in 2024

In 2024, NTS Hengelo processed a total of 8,605 orders for Company X. As shown in Figure 2.1**,** 8,133 orders (94.5%) were new builds, while only 472 orders (5.5%) were classified as repair orders. Despite this relatively small share, repair orders generated €3.5 million in revenue, highlighting their financial relevance even at a limited scale.

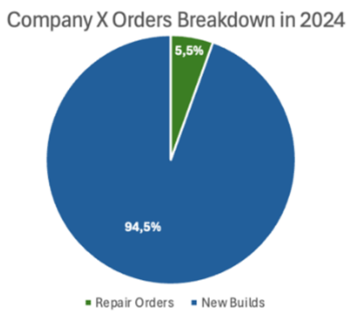

Figure 2.1: Repair vs. new build order share of Company X in 2024

Interviews with stakeholders from both NTS Hengelo and Company X emphasize the growing strategic and sustainability-driven importance of repair. According to the Company X account lead, the company has long recognized the value of component reuse. Company X's former Chief Technology Officer (CTO) initiated a program to store used components in a dedicated warehouse. As a result of storing all these components, a formal repair and reuse department evolved with its own functions and responsibilities.

Company X is currently trying to encourage its tier-1 suppliers, including NTS Hengelo, to share their willingness for repair and reuse. The Company X logistics supplier manager noted that scaling such initiatives offers a strong business case, benefiting both financial outcomes and circularity goals. These two new KPIs serve as tools to increase accountability and promote reuse, and their detailed structure is discussed in the next section.

Additional interviews further highlighted the long-term relevance of repair. An NTS Hengelo quality engineer, who coordinates directly with Company X, pointed out that many more products could potentially be repaired. He further supported this claim by stating that an average Company X product has a designed functional lifespan of seven years, with approximately 95% of these products still in operation after 30 years. This indicates a substantial and growing pool of components suitable for reuse.

However, the same Company X account lead cautioned that “if repair and reuse initiatives are not formally integrated into a company’s processes and values, they risk being forgotten in 2–3 years.” In that light, the introduction of formal KPIs such as ROLT and repair rate provides both accountability and an opportunity to elevate repair to a more prioritized operational level.

2.2. Measurement and Performance of ROLT KPI

As stated in **Section 2.1**, Company X introduced two formal sustainability-related KPIs for its suppliers in early 2025 to encourage the integration of reuse into the supplier network: *Repair Order Lead Time (ROLT)* and *Supplier Repair Rate*. This section explains the structure and logic of the ROLT KPI in detail, as it is the primary focus of this thesis.

Instead of counting how many orders are on time, the ROLT KPI focuses on the total value in euros of repairs completed within their agreed time window. If a part is returned within the set number of days specified in the repair order, it is marked as “Inside ROLT”**;** otherwise, it is classified as “Outside ROLT.” The final KPI score represents the percentage of the total repair value that was delivered on time, presented in Figure 2.2.

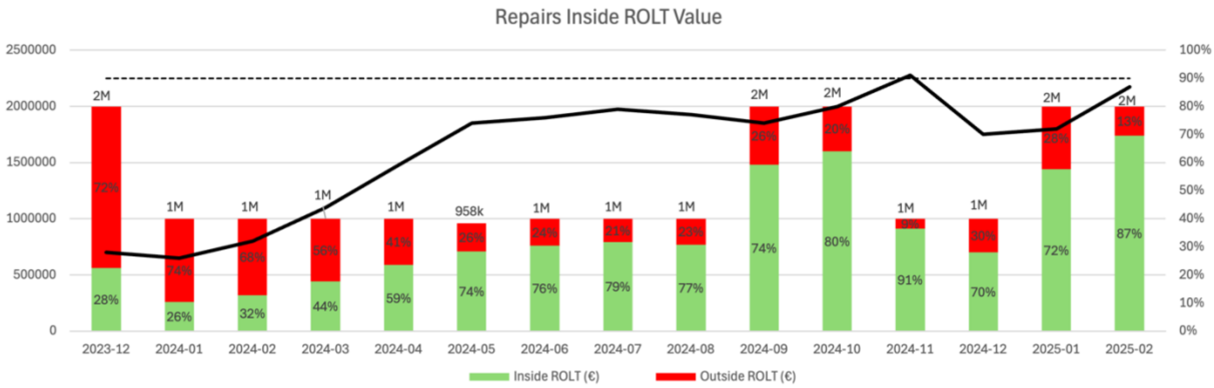

*Figure 2.2**:** NTS’s Hengelo ROLT Performance Overview*

The green bars represent the total repair value delivered within the agreed lead time ("Inside ROLT"), while the red bars represent the value delivered outside the lead time ("Outside ROLT"). The left vertical axis shows the repair value in euros. The black line indicates the overall ROLT compliance rate as a percentage, benchmarked against the 90% target (dashed line), with percentages shown on the right vertical axis. Percentages inside the green and red bars further illustrate the value proportion of on-time and late repairs respectively.

The target value for the ROLT KPI is set at 90%**,** meaning that at least 90% of the total repair value must be returned within the agreed lead time.

In contrast, the second sustainability-related KPI Supplier Repair Rate, measures the success rate of supplier repairs based on value. It is calculated using the following formula:

$$\frac{Total\ value\ of\ successful\ repairs}{Total\ value\ of\ all\ returned\ parts} \times 100\%$$

Equation 2.1: Supplier Repair Rate KPI Calculation

This KPI has a custom target per vendor and classifies performance based on deviation from that target. NTS Hengelo currently scores a deviation of only 0.5% below the target (99.5%

success rate), placing it well within the acceptable band. Therefore, the Supplier Repair Rate is not considered a performance concern and will not be the focus of this research.

In contrast, the ROLT KPI shows clear performance gaps. Although performance improved over time, it consistently fell short of the 90% target. As visualized in Figure 2.2, ROLT performance throughout 2024 improved over time. The left Y-axis represents the total repair value (in euros) per month, also shown numerically above each bar. The right Y-axis corresponds to the black line, which tracks the monthly percentage of repairs completed on time (Inside ROLT)**.** Each bar is divided into a green segment (on-time repairs) and a red segment (late repairs), with the percentages labeled inside the bars to indicate the proportion of each category. Figure 2.3 reveals that the early months of 2024 showed poor on-time rates, with only 26% in January and 32% in February. While the trend improved in the second half of the year, a consistent target level was not reached.

To define the current performance baseline of NTS Hengelo, with agreement with the stakeholders of NTS Hengelo, this study uses the average ROLT compliance rate of the last three months of 2024 (October–December), resulting in a value of **80.3%**. These months reflect a relatively stable operational state after the KPI's initial implementation. These chosen months are consistent unlike early 2024, which involved setup disruptions. Also, it avoids the inclusion of months in 2025 since they fall outside the scope of the analyzed dataset.

The visual clearly shows that while NTS Hengelo has made progress toward the 90% benchmark, gaps still exist. These persistent delays form the basis for further investigation in this thesis.

To conclude, while both KPIs introduced by Company X aim to promote sustainable supplier practices, this thesis will focus solely on ROLT performance. The Repair Rate KPI is already being consistently met. As for broader structural issues, such as prioritization conflicts with new builds or under-integration of sustainability KPIs, they are acknowledged but fall outside the scope of this research. Instead, the next section explains why this thesis targets bottlenecks within the current repair process. Thus, offering practical opportunities to reduce delays and improve compliance.

2.2.1. Justification for Focusing on ROLT KPI

This research explicitly concentrates on the operational delays within the repair process at NTS Hengelo that contribute to the failure to meet the ROLT target. The primary objective is to identify recurring bottlenecks within the internal repair workflow. Subsequently, proposing targeted and feasible interventions to decrease repair lead time. These bottlenecks are considered directly solvable within the research scope and timeframe.

Moreover, during internal discussions, the Company X account lead indicated that consistently achieving the 90% ROLT KPI may open the door to additional repair volumes being assigned to NTS Hengelo. This would not only boost financial returns but also further solidify NTS Hengelo's role in advancing circularity efforts, thus creating a win-win outcome for both companies.

Although the focus is placed on process-level inefficiencies, it is important to acknowledge that broader structural challenges also influence ROLT performance. However, these external issues fall outside the scope of this study.

One such issue is the conflict between different KPIs. The quality engineer at NTS Hengelo noted that the logistics and planning teams often prioritize new build orders to meet the Supplier On Time and In Full (OTIF) KPI. This metric requires that 95% of new builds be delivered on time. As a result, it creates a clash in NTS Hengelo stakeholders' priorities. The repair orders, despite their growing strategic relevance, are frequently deprioritized in day-to-day scheduling. This prioritization dynamic has a tangible impact on the timely handling of repairs, especially in the cleanroom since repair orders comprise only 5.5% of total Company X-related orders in 2024.

The repair coordinator at NTS Hengelo stated an additional constraint. He explained that when repair orders cannot be fulfilled due to technical constraints, the affected parts are returned to Company X. Once these parts are shipped back, NTS Hengelo has no visibility regarding their subsequent handling. This lack of feedback limits opportunities for learning and continuous improvement. Furthermore, Company X expects NTS Hengelo to follow the Technical Build Document (TBD) as closely as possible, even for repaired parts. Due to wear and tear on returned components, strict adherence is not always feasible. In such cases, a Deviation Note (DN) must be submitted. If a DN is not logged and Company X later identifies deviations, formal complaints may be filed even when the issues are mainly cosmetic. Although Company X is generally accommodating of such deviations following internal discussions, the process imposes an additional administrative burden.

Another structural challenge lies in the complexity of managing multi-tier supply chains. The quality engineer described a case in which a component passed through five different suppliers before reaching Company X. NTS Hengelo was responsible for tracing the issue back through the entire chain, which resulted in significant delays. Moreover, coordinating corrective actions across multiple suppliers becomes a time-consuming and uncertain endeavor since there are no strict deadlines for supplier responses

While these contextual and organizational factors undoubtedly affect repair performance, they involve strategic, inter-organizational coordination that extends beyond the scope and control of this research. Consequently, this thesis will not attempt to address them directly. Instead, the research will focus on operational bottlenecks within the internal repair process, specifically those process steps that consume excessive time and contribute to missed ROLT targets.

2.3. Repair Process Description

It is essential to first understand the structure and sequence of the current process to accurately diagnose where delays occur in NTS Hengelo's repair operations. Figure 2.3 presents a BPMN (Business Process Model and Notation) diagram that visualizes the repair process. Moreover, it highlights each stakeholder's responsibilities and the critical decision points across the flow.

The diagram uses standardized symbols to represent different process elements, such as tasks and gateways. These are explained in the legend beneath the diagram. For instance, gateways, represented by diamonds, indicate decision points such as whether a quote is needed or whether a repair should be scrapped. The swimlanes segment responsibilities across different departments, thus clarifying which stakeholder (e.g., sales team, logistics team, quality engineers) owns each step. This layout improves the visibility of cross-departmental interactions and helps identify where coordination delays may occur.

BPMN diagrams are commonly used to improve visibility and communication across processes by mapping the interactions of different organizational roles (Dijkman et al., 2008). In this case, the diagram lays the foundation for understanding the repair process and how specific repair paths (P64 and P65) evolve.

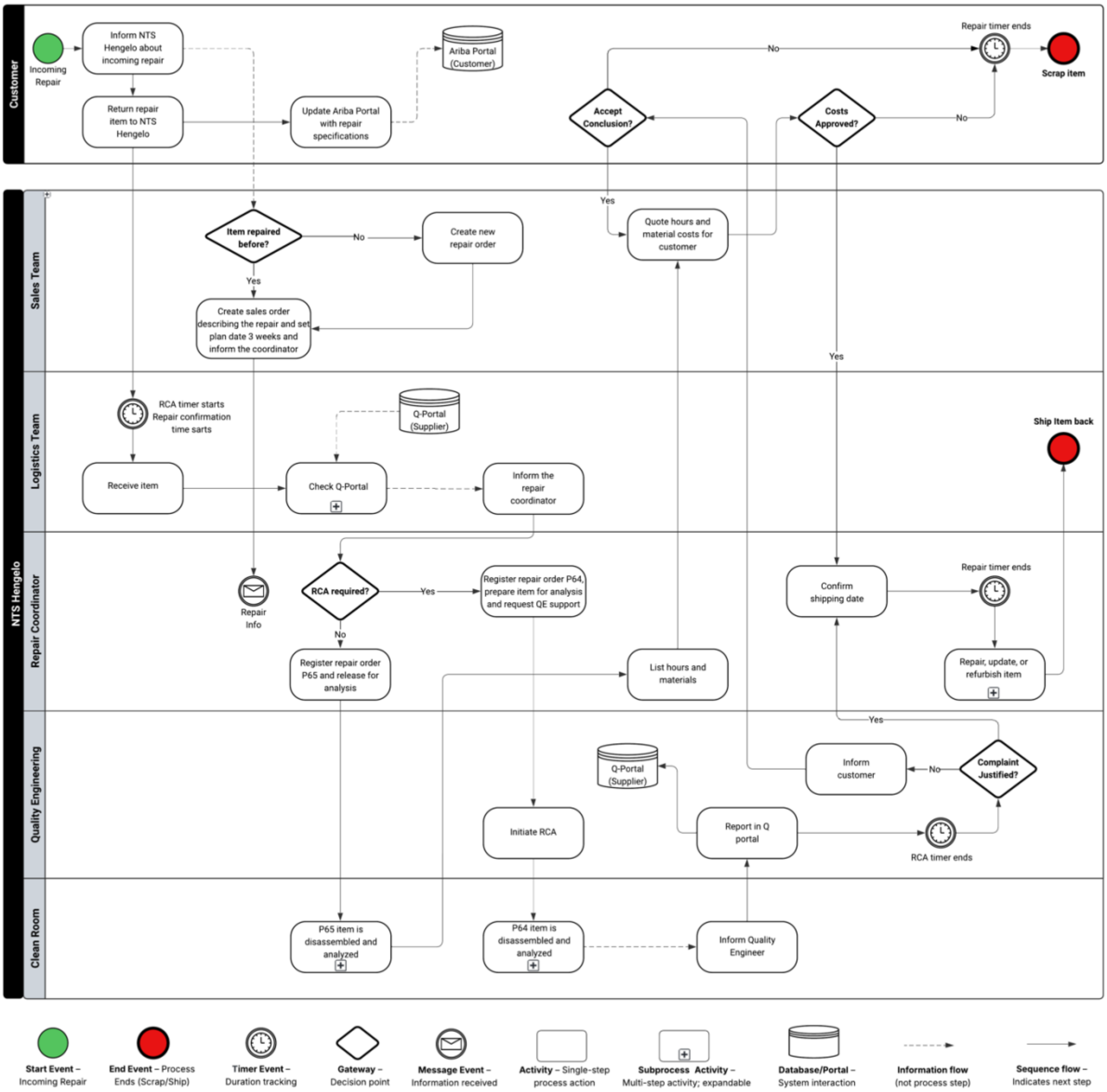

Figure 2.3: Repair Process at NTS Hengelo (BPMN Format)

The repair process begins when Company X initiates a repair request. As shown by the green circle in Figure 2.3, the customer informs NTS Hengelo of the incoming repair and updates the Ariba portal with specifications. The Ariba portal serves as a communication channel, mainly used for quoting material costs, labor hours, and expected delivery timelines.

The sales team first determines whether the item has been previously repaired. If the repair is recognized, a unique identifier code is assigned. If it is a new case, a repair order is first created then it is registered with a new addition: “R” at the beginning of the unique code. This identification process ensures that future repairs of the same item can be efficiently tracked.

Following this, a three-week window begins in which NTS Hengelo is expected to confirm the repair plan to Company X.

Concurrently, the repair coordinator is informed of the incoming item, and the logistics team physically checks it in. At this stage, the Q-Portal system is consulted to verify the initial problem description. Q-Portal functions as a digital logbook used exclusively between NTS Hengelo and Company X. It allows Company X to track a repair's progress through various checkpoints, while NTS Hengelo is responsible for updating each milestone as it occurs.

Based on the initial repair description stated on the Q-Portal, the repair coordinator assesses whether a Root Cause Analysis (RCA) is necessary. The decision to perform an RCA dictates the classification of the repair as either a **P64** or **P65** order. If RCA is required, the repair is registered as a **P64** order. Thus, represents a complaint-based repair. In this case, the item undergoes detailed examination within the cleanroom to determine whether the issue is caused by a manufacturing fault or is due to wear and tear. If the defect is attributed to NTS Hengelo, it falls under warranty, thus NTS Hengelo bears the repair cost. If the defect is deemed to be the customer's responsibility, a cost quotation is sent to Company X for approval. Any refusal leads to NTS Hengelo billing for only the RCA labor and materials. After this step, NTS Hengelo has no insight into the item's final handling by Company X.

On the other hand, if RCA is not needed, the repair is classified as a **P65** order. Thus, indicating a standard repair due to aging or functional wear. These repairs bypass the complaint analysis stage since an RCA is not needed and follow a more direct path. This path generally results in lower lead times. In both P64 and P65 flows, once the issue is diagnosed and accepted, the coordinator sets a shipping date. Meaning that NTS Hengelo has 30 calendar days to complete the repair and return the item to Company X. The BPMN diagram clearly illustrates these operational differences between P64 and P65 orders, particularly in the roles played by the cleanroom and quality engineering teams.

In reviewing 2024's repair order data, it became evident that a substantial portion of both P64 and P65 orders relate to discontinued items, as visualized in Figure 2.4.

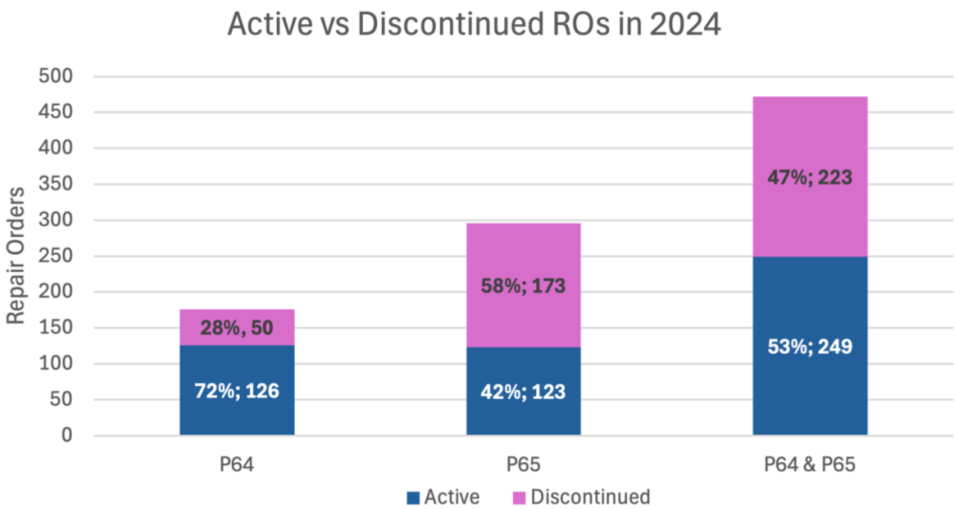

Figure 2.4: Breakdown of Active vs Discontinued Repair Orders in 2024

The bar chart displays the number and percentage of repair orders tied to discontinued (purple) versus active (blue) items. Notably, two discontinued modules comprise a large share of the P64 and P65 orders: **Yieldstar** and **Dampers**. Yieldstar repairs and their subcomponents are gradually being transferred to NTS Singapore throughout the first half of 2025. On the other hand, the production and repair of Dampers were fully moved to NTS Drachten in April 2025. These shifts were implemented by Company X to streamline logistics and consolidate complex module servicing under one location.

Due to these ongoing transfers, repairs associated with discontinued items will not be prioritized in this thesis's bottleneck analysis. Addressing bottlenecks in processes that are being phased out would not generate sustainable improvements for NTS Hengelo. Accordingly, these discontinued orders are highlighted in purple in the analysis chapters and excluded from further intervention considerations.

While these discontinued items fall outside the scope of the current analysis, their previous dominance in both new build and repair orders had a significant operational impact at NTS Hengelo. As their volume declined, the associated workload decreased too. This resulted in the layoff of several cleanroom workers. Although this thesis focuses on identifying and solving operational bottlenecks in the repair process, improving repair lead time performance and consistently achieving the 90% ROLT KPI can have broader strategic implications. A more reliable and timely repair process could raise NTS Hengelo's supplier performance rating and make a compelling case for being entrusted with additional repair volumes moving forward.

Supporting this strategic outlook, interviews with Company X's account lead (**Section 2.1**) revealed the recent creation of a dedicated department that manages the growing stock of reusable components stored in their warehouse. Company X's account lead stated that this stock includes items originally manufactured by NTS Hengelo. This reinforces the long-term relevance of optimizing repair operations and further emphasizes the importance of this thesis's objective: laying the operational groundwork for identifying and resolving bottlenecks to support sustainable and long-term repair performance.

Chapter 3 will now introduce the theoretical framework used to identify bottlenecks, while Chapter 4 will apply this framework to NTS Hengelo's 2024 repair order data.

3. Bottleneck Identification Framework

This chapter establishes the methodological foundation required to answer the core sub-research question 3 presented in **Chapter 4**: *"What are the major bottlenecks in NTS Hengelo's repair process?"*

Sections 3.1 and **3.2** address *supporting sub-question 3.1: "What structured methods can be used to identify process bottlenecks aimed at improving the repair process performance at NTS Hengelo?"* by reviewing and evaluating bottleneck identification methods grounded in literature. **Section 3.3** answers *supporting sub-question 3.2: "Which of these bottleneck identification methods are suitable for application to NTS Hengelo's repair process?"* through a comparative framework and structured selection of the most appropriate methods for the NTS Hengelo context. Together, these sections lay the conceptual and methodological groundwork required for the applied analysis in **Chapter 4**, where the selected methods are used to identify and analyze the key process bottlenecks.

3.1. Theoretical Approaches to Bottleneck Identification

The bottlenecks within the repair process must first be identified to improve the repair lead time compliance at NTS Hengelo. Bottlenecks are process stages where constraints limit overall efficiency, thus leading to delays and reduced overall performance (Ananta, 2023). There are various methodologies that specialize in identifying bottlenecks, and each offers unique insights into process inefficiencies. This section presents an overview of common bottleneck identification methods and categorizes them into traditional and emerging approaches.

3.1.1. Introduction to Common Bottleneck Identification Methods

The most commonly used methods can be grouped into two main categories:

1. Traditional Bottleneck Identification Methods: Value Stream Mapping (VSM), DMAIC (Define–Measure–Analyze–Improve–Control) framework, and Pareto Analysis.

These methods have been widely used for over two decades and are grounded in Lean, Six Sigma, and process engineering literature. They are often used in different types of environments due to their simplicity and interpretability.

2. Emerging & Data-Driven Methods: Multi-Criteria Decision-Making (MCDM), Process Mining, and Bottleneck/Gemba Walks.

As for these emerging approaches, they are often more updated and driven by advances in data analytics, real-time process tracking, and decision-support frameworks. They appear more frequently in recent literature and are especially suitable for dynamic or digitally tracked processes.

Each method is further examined in **Section 3.2** in terms of its conceptual foundation, application across selected studies, practical relevance, and potential applicability. These methods are drawn from recent academic and industrial literature and can be used to systematically assess and potentially pinpoint the bottleneck(s) affecting delays in the repair lead times at NTS Hengelo.

3.2. Review of Bottleneck Identification Methods

3.2.1. Value Stream Mapping

Value Stream Mapping (VSM) is a Lean methodology typically used to summarize, present, and communicate the flow of materials and information throughout a process (Mishra et al., 2020). According to Mishra et al. (2020), VSM can systematically identify and remove bottlenecks. Moreover, VSM categorizes these bottlenecks into different types of waste such as delays, redundancies, and non-value-adding activities (Singh & Singh, 2013).

Originally developed in 1995, VSM is now widely applied in various industries due to its assistance in identifying waste in process flows and addressing the bottleneck accordingly (Singh & Singh, 2013). One of the main features of VSM is that it creates both a current state and a future state map (Liu et al., 2020). Moreover, it enables organizations to pinpoint bottlenecks and design targeted improvements (Lu et al., 2011). VSM also focuses on system-wide performance by analyzing key metrics such as cycle time, lead time, and work-in-progress (WIP) (Seth & Gupta, 2007).

Based on the literature, it was heavily used across different sectors such as automotive, food processing, and manufacturing. For instance, Singh & Singh (2013) used VSM in an auto parts factory to reduce cycle time and WIP. As for more complex environments, VSM was integrated with simulation or MCDM. For example, Lu et al. (2011) combined VSM with MCDM techniques under demand uncertainty to evaluate and redesign a lean pull system in electronics assembly. This hybrid approach allowed more accurate prioritization of improvement areas based on weighted performance indicators.

Across the studies, a common benefit of VSM was its accessibility and ease of use. For example, Seth & Gupta (2007) highlighted that the VSM can be implemented easily for almost any activity or stage in businesses. However, Lu et al. (2011) stated that using VSM solely without a supporting method makes it hard to come to a concrete conclusion from different scenarios.

After analyzing the literature, VSM can offer a practical way to visualize NTS Hengelo's repair process and pinpoint delays affecting the company's ability to consistently meet the 90% ROLT KPI set by Company X. Drawing from the literature, VSM is highly applicable to NTS Hengelo due to the fact that timestamp data of the different stages of the repair process is available. As shown in the literature, VSM is especially effective in structured environments like NTS Hengelo, where improving flow is key to enhancing lead time performance.

3.2.2. DMAIC Framework

The Define-Measure-Analyze-Improve-Control (DMAIC) framework is a tool that offers a structured methodology for identifying and addressing the bottlenecks (Karout & Awasthi, 2017). Sharma et al. (2022) stated that the utilization of DMAIC alongside other tools improves the entire process by reducing waste, total waiting time, lead time, and defect rates.

Moreover, DMAIC has proved that it is effective across various manufacturing domains (Sharma et al., 2022). Sharma et al. (2022) successfully applied DMAIC alongside other tools such as VSM and Pareto Charts in an Indian automobile lighting firm. This integration led to a 53% reduction in defect rates, which is a notable increase in production efficiency and it further improved machine utilization. This case highlights how DMAIC phases can incorporate a supporting method, such as structured waste categorization to pinpoint process inefficiencies. Based on the literature, the systematic nature of DMAIC makes it especially relevant for complex environments like NTS Hengelo, since interrelated inefficiencies may exist in the current repair process.

Inferred from the literature, DMAIC can be highly relevant to NTS Hengelo’s objective of improving its repair order lead time (ROLT) compliance. The framework offers a systematic way to:

- **Define** delays and identify key stakeholder expectations (e.g., Company X's 90% ROLT target)
- **Measure** throughput, backlog, and timing data
- **Analyze** the root causes behind bottlenecks and inconsistencies
- **Improve** performance through targeted interventions
- **Control** results via standardized monitoring and control charts

3.2.3. Pareto Analysis

Pareto Analysis suggests that a small number of causes are often responsible for the majority of problems, so its focus should be limited to a small number of important factors (Krishnan et al., 2022). However, it was typically used as a supporting tool rather than a primary diagnostic method. The Pareto analysis helps analyze and identify the most significant factors affecting process bottlenecks (Sharma et al., 2022). In a recent study by Krishnan et al. (2022)**,** Pareto charts were used in a Lean Six Sigma project to identify machines and defect types contributing most to production rework. The analysis revealed that just three machines caused over 80% of the rework, thus enabling the team to focus improvement efforts efficiently.

In NTS Hengelo’s context, Pareto Analysis can be employed to analyze repair data such as late repair orders, causes of rework, or workstation delays. Then the issue derived would be ranked by frequency or impact. However, Pareto’s limitations are clear based on the different articles. Mainly that it does not reveal root causes or process dynamics**.** In this research, Pareto Analysis will be considered a supporting tool which is useful for prioritizing known issues within NTS Hengelo’s repair process, since the literature infers that it is insufficient for a standalone bottleneck identification.

3.2.4. Multi-Criteria Decision-Making

Multi-Criteria Decision-Making (MCDM) is a structured framework used to evaluate and rank multiple scenarios (such as manufacturing problems) based on several criteria (Singh et al., 2021). This approach is particularly useful in complex industrial environments where decision-making must consider trade-offs among factors like cost, quality, lead time, and demand variability (Singh et al., 2021). MCDM provides a rational basis for selecting the most effective bottleneck resolution or improvement strategy by incorporating both quantitative and qualitative indicators (Singh et al., 2021).

In the study by Lu et al. (2011), MCDM was integrated with a hybrid Taguchi-TOPSIS method to support robust decision-making under demand uncertainty. This combination enabled the researchers to evaluate multiple production scenarios and identify an optimal lean pull strategy. The study revealed that integrating simulation with MCDM allows for rigorous comparison between current-state and future-state production setups. As a result, both transparency and robustness improved in the decision-making process. The second article (Singh et al., 2021) reinforces this application by illustrating how MCDM helps prioritize operational decisions where numerous factors affect bottleneck performance. Singh et al. (2021) highlighted that using ranking algorithms enables firms to address uncertainty while aligning operational parameters with strategic objectives.

In the context of NTS Hengelo, MCDM could be a valuable method for evaluating different bottleneck mitigation scenarios. Its suitability would be dependent on the availability of data regarding variable lead times, part availability, technician workload, etc. If such data is available, then MCDM would be suitable since it offers a structured way to weigh these competing factors. It would be especially relevant in the later stages of this thesis, when potential interventions identified through a different method need to be assessed for feasibility and impact.

3.2.5. Process Mining

Process Mining is a data-driven methodology that extracts knowledge from event logs recorded by information systems to discover, monitor, and improve real processes (Singh et al., 2021). Unlike traditional process analysis methods, Process Mining leverages actual process execution data to provide insights into how processes behave in reality (Singh et al., 2021). It integrates principles from data mining, machine learning, and workflow management to reconstruct and analyze process flows, detect bottlenecks, and identify deviations from expected performance (Singh et al., 2021).

In the healthcare case study by Singh et al. (2022), Process Mining was applied using *Celonis* software to analyze event-log data from 165 eye surgery patients. The study identified a significant bottleneck by reconstructing the surgical process flow. The results revealed that there was a delay of 59 minutes between patient arrival and the start of anesthesia. This delay played a big part in inefficiencies in the overall surgery scheduling. The method not only revealed where delays occurred but also quantified them using throughput times, thus offering a precise understanding of process lags. The visualization capabilities of the tool enabled stakeholders to interactively explore process paths, thus helping facilitate shared decision-making when prioritizing interventions.

At NTS Hengelo, Process Mining can offer a highly accurate picture of the current repair process by analyzing digital footprints such as timestamps from the repair database. For example, it can reveal excessive waiting times between repair completion and logistical planning. Given that the repair process is structured, Process Mining can uncover hidden inefficiencies and compare the actual process execution to the intended flow. This objective and data-driven identification of bottlenecks can support NTS Hengelo in addressing specific delays that prevent achieving the 90% Repair Order Lead Time (ROLT) compliance target set by Company X.

3.2.6. Gemba Walks

Gemba walks follow the concept of “walk the flow, create the flow”. This approach means that observers physically monitor the assembly line and identify areas for improvement from the shop floor perspective (Sangwa and Sangwan, 2023).

Sangwa and Sangwan (2023) showed in their study how Gemba Walks were a critical component of a lean improvement initiative in a complex automotive component assembly line. The researchers used the walks in the assembly line to physically map out inefficiencies and identify waste. Moreover, in the study, Gemba Walks supported qualitative techniques such as the "Five Whys" and "5W2H" to identify root causes behind problems like high cycle times, material handling issues, and excess work-in-progress (WIP). Their findings led to the development of an integrated Value Stream Map and twenty kaizen improvement bursts. As a result, leanness and productivity improved significantly.

The repair environment at NTS Hengelo involves multiple stakeholders, tight deadlines, and potential inefficiencies hidden in day-to-day operations. So the implementation of Gemba Walks can play a strategic role in this context by enabling direct observation of possible deviations from day-to-day procedures. Additionally, it can identify redundant tasks and involve employees in the problem-solving process.

These literature-backed insights provide a solid foundation for method evaluation and selection. The next section synthesizes these findings into a comparative framework to determine which methods are most suitable for the NTS Hengelo context.

3.3. Method Comparison and Selection

After presenting and discussing the theoretical foundations and literature insights for each bottleneck identification method, this section integrates the findings from **Section 3.2** into a comparative framework. A conceptual overview diagram summarizes how traditional and emerging methods contribute to bottleneck detection. Subsequently, a comparative table evaluates the six methods based on literature-backed criteria: conceptual foundation, practical fit with NTS Hengelo, and literature-backed advantages and limitations. Based on this structured analysis, the most suitable methods are selected for application in the bottleneck identification strategy. The rationale behind the selection of the method(s) is also examined.

3.3.1. Conceptual Overview Diagram

A conceptual framework (Figure 3.1) is developed to consolidate the various bottleneck identification methods explored in the literature. This diagram visually integrates traditional and emerging approaches, thus illustrating exactly how they collectively support the detection of bottlenecks in the repair process at NTS Hengelo. Note that the arrows indicate how each method contributes insights into the integrated bottleneck detection framework.

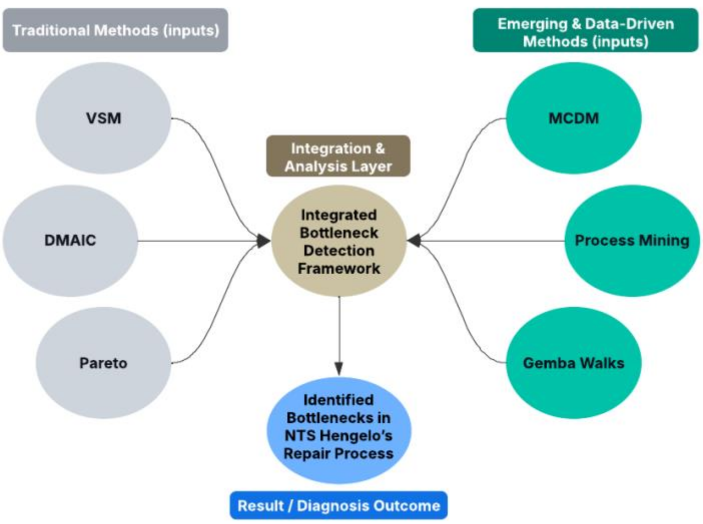

Figure 3.1: Conceptual Overview Diagram for Bottleneck Identification

3.3.2. Comparative Analysis Table

Building upon the conceptual overview, a detailed comparative analysis is created to evaluate each method's theoretical foundation, fit with NTS Hengelo, and literature-based advantages and disadvantages. This structured comparison ensures that method selection is grounded in academic evidence rather than subjective preference.

Method	Overview Based on Literature	Fit with NTS Hengelo	Literature-Based Pros	Literature-Based Cons
Traditional Methods				
VSM	Widely used Lean tool that visually maps processes to identify non-value-adding steps and bottlenecks. It is commonly applied in manufacturing and repair settings.	High – the repair process is structured and timestamped, allowing process steps to be mapped and durations to be analyzed using Excel.	Simple to use; helps visualize entire process. Effective for identifying delay-prone steps in structured environments.	May oversimplify complex systems. Lacks quantitative depth without support from additional methods.
DMAIC	Structured, five-phase Six Sigma framework used for systematic problem-solving, performance improvement, and root cause analysis.	Moderate – suitable as a framework for improvement but not directly as a bottleneck detection tool.	Structured and comprehensive. Enables continuous improvement and stakeholder involvement Adaptable to many sectors.	Time- and resource-intensive. Requires training and full-cycle data. Assumes problem is well-defined.
Pareto Analysis	Pareto Analysis helps identify the most frequent or impactful issues contributing to inefficiencies.	High – useful for ranking frequent or high-impact delays. Complements other tools for initial diagnosis.	Quick to implement. Helps prioritize major delay causes. Frequently used in maintenance and quality contexts.	Does not identify root causes, often used as a supporting rather than standalone tool.
Emerging Data Driven Methods				
MCDM	MCDM techniques help evaluate and rank alternatives based on multiple conflicting criteria. It is frequently applied in decision-making under uncertainty.	Low to Moderate – useful for evaluating solution options, but not designed for identifying root causes or delays.	Supports rational and robust decision-making. Combines qualitative and quantitative inputs for scenario comparison.	Complex to implement. Requires predefined criteria, weights, and data input. Not intuitive for early-phase diagnostics.
Process Mining	Process Mining analyzes digital event logs to uncover actual process flows, bottlenecks, and deviations from expected performance.	Moderate – data format aligns conceptually, but absence of specialized tools limits full implementation.	Accurate and objective.Uncovers hidden inefficiencies. Handles complex process variants well.	Tool-dependent. Unsuitable without access to event logs and process mining software. Steep learning curve.
Gemba Walks	Gemba Walks are Lean practices involving direct observation of work at the source to gain insights into operational inefficiencies and improvement opportunities.	Moderate – qualitative insights from interviews replicate Gemba's objectives, though not based on physical observation.	Captures first-hand operational insights. Identifies invisible workflow issues; strengthens team involvement.	Subjective. Observation bias risk. Insights depend heavily on observer experience and cooperation of staff.

Table 3.1: Comparative Analysis of Bottleneck Identification Methods Based on Literature & NTS Hengelo Context

3.3.3. Rationale for Method Selection

Based on the comparative analysis in Table 3.1, the rationale for each selected method is presented in this section, highlighting its suitability for this research context. The selection of bottleneck identification methods is made by aligning theoretical insights with the practical requirements and data availability at NTS Hengelo.

Rather than beginning with a predefined approach, this research began by examining the requirements of effective bottleneck identification as defined in academic and industrial studies. After this thorough examination, an analysis of the available tools, data structures, and stakeholder input is conducted.

The literature review revealed a wide range of approaches. These methods can broadly be categorized into traditional, lean-based methods (e.g., VSM, Pareto Analysis, DMAIC) and emerging, data-driven methods (e.g., Process Mining, MCDM, Gemba Walks). Each was evaluated on four dimensions: theoretical foundation, practical application in literature, data and resource requirements, and contextual fit with the current setup at NTS Hengelo.

Based on this evaluation, two methods are selected for their demonstrated suitability across both theory and context.

Pareto Analysis

While not sufficient as a standalone diagnostic method, Pareto Analysis complements VSM by offering a prioritization mechanism. It has been repeatedly used in practice to identify the “vital few” issues responsible for the majority of delays (Sharma et al., 2022). In the context of NTS Hengelo, Pareto helps narrow the focus to high-impact problems identified through the process map. This is suitable since there are recurring repair types and variability is observable.

Process Mining (Adapted)

Singh et al. (2021) introduce the concept of Design for Process-Mining (DFPM), where decentralized data collection using simple tools like Google Sheets or LibreOffice can be used to manually create structured logs suitable for process mining. This recommendation is based on the fact that system-based event logs are unavailable from the company.

Building upon this principle, this thesis adapts process mining by manually analyzing ERP/Excel-based repair logs structured with activity timestamps and durations. While this approach does not replicate full automation provided by specialized software, it maintains conceptual alignment with the objectives of process discovery and bottleneck identification as outlined by Singh et al. (2021).

Excluded Methods and Rationale

Other methods explored in the literature, such as VSM, DMAIC, MCDM, and Gemba Walks, are not selected for bottleneck identification. Although VSM is highly applicable but it is very reliant on a clearly defined future state, which is not available in NTS Hengelo’s system. DMAIC was excluded due to its stronger alignment with improvement implementation rather than bottleneck detection. MCDM is excluded due to its complexity and its primary use in alternative evaluation rather than diagnosis. Gemba Walks, while valuable in qualitative settings, are conceptually addressed through interviews, rather than on-site observation.

By systematically selecting and integrating the most suitable bottleneck identification methods, this section has established a strong methodological foundation for analyzing NTS Hengelo's repair process. **Chapter 4** applies this integrated strategy using VSM, Pareto Analysis, and an adapted Process Mining approach to identify the main process bottlenecks affecting repair order lead time performance.

4. Identifying Bottlenecks Using Selected Methods

This chapter addresses *core sub-Question 4: What are the major bottlenecks in NTS Hengelo's repair process?* It combines quantitative data and qualitative input to systematically uncover the key sources of delay and inefficiency in the repair process using the methods discussed in **Chapter 3.**

The analysis begins with a structured integration of stakeholder insights and internal repair data. The chapter highlights performance gaps and frequent delays by segmenting the dataset and evaluating compliance with the Repair Order Lead Time (ROLT) KPI. Further examination of item-level durations and variability distinguishes consistently underperforming items from single outliers.

A frequency-weighted Pareto approach is applied to prioritize bottlenecks based not only on duration but also frequency. This is followed by a comparison of planned versus actual repair durations with a focus on unproductive time. Thus, shedding light on where systemic inefficiencies may be rooted.

The analysis concludes with a step-by-step investigation of the most problematic repair items. After examining time allocation, productivity levels, and variability at each repair stage, the chapter pinpoints specific steps. These steps include cleanroom analysis, execution, and logistics planning which contribute most to lead time overruns.

4.1. Operationalization of the Analytical Framework

A two-phase analytical framework is developed to systematically identify the key bottlenecks in NTS Hengelo's repair process. This framework combines qualitative insights from stakeholders alongside quantitative analysis of internal repair data. This approach ensures that identified issues are both data-driven and practically validated (Ahmed et al., 2024).

As shown in Figure 4.1, the first phase consisted of exploratory interviews with multiple departments involved in or impacted by the repair process, such as Sales, Repair, Planning, and Company X stakeholders. These discussions aimed to gather diverse perspectives on frequent delays, coordination challenges, and suspected inefficiencies. The outcome of this phase is a set of preliminary hypotheses on likely bottleneck locations and contributing factors.

In the second phase, structured data from completed repair orders in 2024 is analyzed using Excel-based logs. The dataset includes detailed timestamps, repair types, step-level durations, and productive vs. unproductive time entries. This enables the systematic application of three selected bottleneck identification tools. **Pareto Analysis** is conducted to prioritize the repair items responsible for the largest share of total lead time impact, helping to isolate high-frequency contributors to delays. Additionally, an **Excel-adapted Process Mining** approach is applied to compare actual execution timelines against planned durations, enabling the identification of deviations, delay sources, and inefficiencies embedded in the process flow.

After the core analyses are completed, a second round of validation interviews is conducted with the same stakeholder groups. Importantly, these are held after the quantitative results are generated but prior to sharing the findings. This is done to corroborate findings and avoid response bias, thus ensuring that the participants' feedback is consistently independent of the data interpretation (Busetto, Wick, & Gumbinger, 2020). Their input is then used to confirm, refine, or contextualize the identified bottlenecks, strengthening the reliability of the conclusions.

This combined approach of exploratory interviews, structured data analysis, and post-analysis validation creates a solid methodological foundation for identifying bottlenecks.

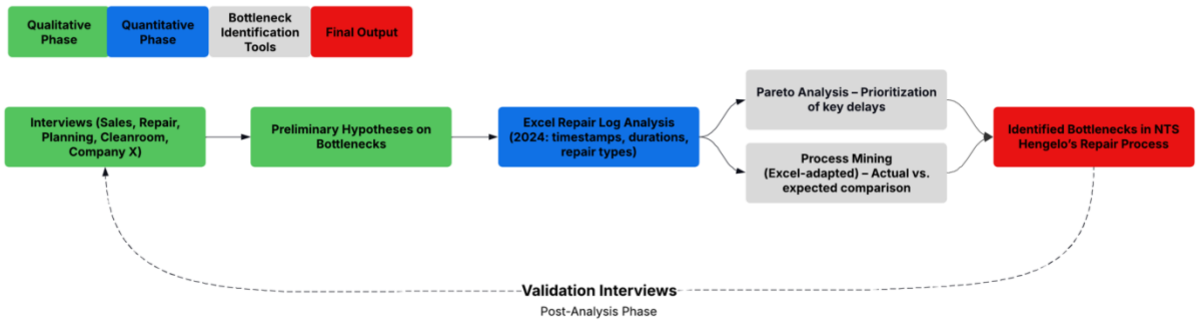

Figure 4.1: Sequential Bottleneck Identification Framework Combining Qualitative and Quantitative Analysis

4.2. Dataset Overview and Segmentation

This section provides an overview of the dataset used to identify bottlenecks in NTS Hengelo's repair process. The ERP data is processed using an OLAP-based approach, where the ICT department structures operational data into multidimensional data cubes. These cubes are accessed via PivotTables in Microsoft Excel to enable dynamic querying, aggregation, and visualization. The process supports slice-and-dice operations and multidimensional analysis (Devangavi & Aggarwal, 2013).

The dataset encompasses repair production orders for the year 2024, with occasional inclusion of late 2023 and early 2025 entries where production orders spanned year boundaries. These niche cases will be explained and highlighted. Each entry contains logs by item code, repair type, item order ID, and step-level operations performed during the repair. For each step, the actual lead time, productive time, and non-productive time are analyzed. Additionally, planned lead times are extracted from the ERP system and reflect company benchmarks based on standard operating procedures.

Timestamps are recorded in calendar days, with step durations calculated accordingly. Although raw timestamps are in hours, the company standardizes lead time values by converting them to days using a 6.4-hour working day, which accounts for lunch breaks and standard non-working intervals. This preprocessing is handled by the company's ICT and data teams prior to delivery. Incomplete repair orders or records with missing steps are filtered out before analysis to ensure data accuracy.

Repairs are segmented into two categories, as explained in **Chapter 2**: (1) P64 (Repair Complaint) initiated due to failure or defect, requiring Root Cause Analysis (RCA). (2) P65

(General/Upgrading Repair), which are standard repairs or upgrades that restore or enhance a component.

Each repair order consists of multiple operational steps. These steps are recorded as timestamped operations in the ERP data. The detailed departmental responsibilities for each step are presented in the BPMN diagram in **Section 2.3**. For clarity, the simplified process flow is presented in Figure 4.2 below:

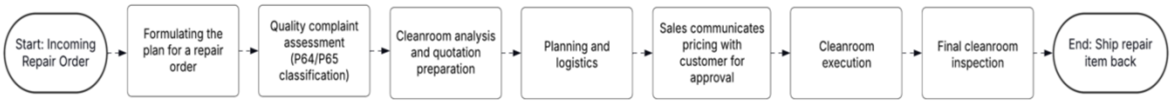

Figure 4.2: Simplified Repair Process Flow at NTS Hengelo

As stated in Chapter 2, there are a total of 472 Company X repair orders from 133 items in 2024. 176 P64 repair orders involving 55 different items and 296 P65 repair orders involving 78 items are identified. After thoroughly analyzing the data, 386 repair orders were completed and properly documented out of the 472 repair orders. Thus, meaning approximately 18.2% of the data is lost, visualized in Figure 4.3. Complete data means the lead times were consistent with all the steps documented correctly.

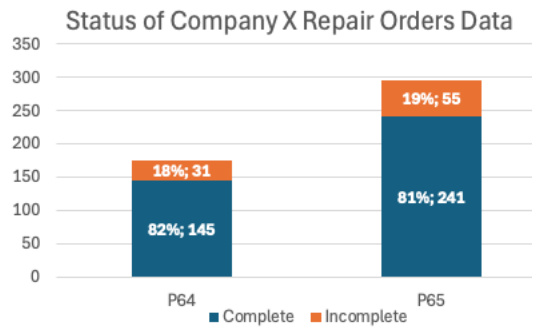

Figure 4.3: Overview of Repair Order Completeness by Type (P64 vs. P65)

145 P64 repair orders and 241 P65 repair orders make up the 386 total complete Company X repair orders, with 120 items across both repair types. While the combined completed total reflects 120 items (50 P64 and 70 P65 items), some items appear in both repair types. Specifically, 21 items are common to both P64 and P65, as illustrated in Figure 4.4.

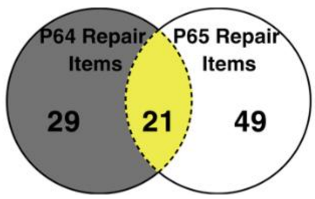

Figure 4.4: Overlap of Items Between P64 and P65 Repair Types

To support interpretability and consistency across all figures in this chapter, a standardized visual distinction is applied when presenting item-level analyses. Items that have been discontinued and reassigned to other NTS sites as of 2025 are visually marked in purple. As previously discussed in Chapter 2, these items are no longer actively handled by NTS Hengelo. Consequently, they fall outside the future scope of the ROLT KPI.

In parallel, items that appear in both P64 and P65 repair orders are consistently highlighted in yellow across this chapter. These recurring items, 21 in total, represent potential high-frequency components subject to multiple types of repair activity. Their dual presence may suggest broader systemic inefficiencies and increase their potential significance in the bottleneck analysis. Tracking these common items throughout the upcoming sections allows for convergence on repair components that are both recurrent and operationally critical.

As a final note, out of the 386 completed repair orders, 187 are currently linked to active items as defined in Section 2.3. These active repair orders form the primary basis for subsequent analyses, given their continued relevance to NTS Hengelo's ongoing operations and KPI tracking. Together, these visual conventions support a clear and traceable link between the dataset's structure, its relevance to current performance targets, and the prioritization logic used in the analysis. The following sections build on this dataset to identify the main bottlenecks.

4.3. KPI Compliance Analysis

While **Section 2.2** described how the ROLT KPI is formally measured based on the total value of repairs delivered within the agreed timeframe, this section adopts a different lens. The analysis here examines the number of completed repair orders that met or exceeded the 51-working-day target in 2024 rather than focusing on monetary value. This shift allows for a more detailed investigation of delay patterns by item and repair type. The analysis pinpoints potential bottlenecks and sets the stage for deeper root-cause exploration at the process-step level by identifying which items and orders most frequently fall outside the ROLT window.

All completed P64 (Repair Complaint) and P65 (General/Upgrading Repair) orders for Company X in 2024 are filtered and analyzed to evaluate compliance. The first pie chart in Figure 4.5 on the left displays the ROLT performance for P64 repairs. It reveals that out of 145 completed orders, 75 (52%) exceeded the 51-day threshold, while 70 (48%) met it. This performance falls significantly short of the 90% compliance target.

In contrast, the second pie chart in the middle shows that P65 repairs performed considerably better. Out of 241 completed P65 orders, 195 (81%) were completed within the 51-day target, and only 46 (19%) exceeded the KPI threshold. This result is much closer to the acceptable performance level and highlights a significant disparity in lead time management between the two repair types, yet it is still below target.

The reason P65 repairs perform better than P64 repair orders is a result of P64 repair orders having an extra step (quality complaint assessment), the second step in Figure 4.2 in Section 4.2. P64 repair orders are regarding a complaint, unlike P65 repair orders, which are concerned with upgrades or refurbishment. As explained in **Section 2.3,** a root cause analysis (RCA) is done for every P64 order to identify whether the complaint against NTS Hengelo is valid or the customer should be held financially liable instead. The total performance of both types of repairs against the KPI in 2024, visualized in the pie chart on the right, shows that 121 repair orders exceeded the 51-day limit. 265 repair orders were done in time, thus 69% of repair orders were within the agreed lead time. However, it is important to note again that these values and percentages strictly cover repair orders in 2024. Also, it covers discontinued items, and the ROLT KPI was not formally introduced until 2025. Hence why the focus is not on criticizing the performance but on having quantitative data that provides an idea of the frequencies and possible bottlenecks.

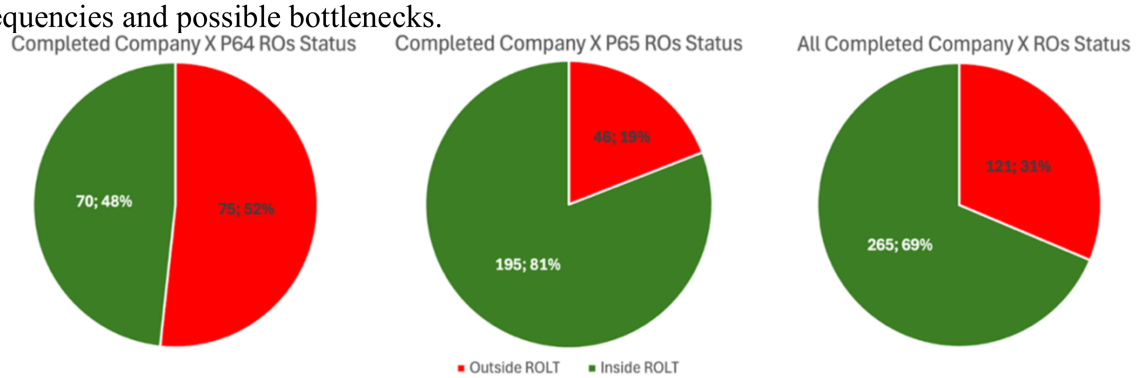

Figure 4.5: ROLT Compliance Status of Completed Repair Orders in 2024

Beyond high-level compliance, the dataset is further examined to determine which items contributed most to the delays. For the 75 delayed P64 orders, 35 items are a result of these delays. Among the 46 delayed P65 orders, 22 items are involved. Eight items are found to contribute to delays in both categories, with 51 corresponding repair orders making up 42% of the delays.

Table 4.1 presents a frequency table of the eight shared items that were late in both repair types. Among them, the five active items are highlighted in yellow, supporting traceability across the chapter, while the discontinued ones are marked in purple. Their dual appearance across repair categories strengthens the hypothesis that they represent structural inefficiencies or critical failure points within the repair process. Identifying and addressing the delays associated with these items may result in meaningful improvements to overall ROLT performance.

Common Late Items Across P64 & P65	Frequency	Status
ECHO	2	Active
BRAVO V1	4	Active
BRAVO V2	6	Active
CHARLIE	5	Active
FOXTROT	14	Discontinued
GOLF	3	Discontinued
ALPHA V2	14	Active
HOTEL	3	Discontinued

Table 4.1: Common Late Repair Items Across Both P64 and P65 Orders

They establish that P64 repairs are a primary concern due to poor ROLT compliance and emphasize the significance of the shared high-impact items across both repair types. The next section narrows the scope by analyzing the average duration and variability of each item to further investigate these delays. This analysis allows the identification of items that consistently exhibit long repair times. More specifically, it points out items with high average durations and low variability, which may indicate systematic bottlenecks rather than incidental or fluctuating delays.

4.4. Item-Level Duration and Variability Analysis

Scatter plots are created for P64 and P65 repair orders to identify which items exhibit the highest average lead time durations and variability. This analysis focuses on items with multiple occurrences in 2024, since items with only a single observation may not provide reliable estimates of variability. According to the Law of Large Numbers, small samples (especially single data points) are unlikely to reflect true underlying characteristics and may lead to misleading conclusions (Investopedia, 2025). Therefore, any item with only one occurrence is excluded from the visual analysis.

29 of the 50 P64 items meet the criteria for inclusion in the scatter plot: having more than one repair order. Similarly, 42 of the 72 P65 items qualify for analysis based on these same thresholds. Items not meeting these conditions are excluded to ensure that the visualizations reflect only those cases where lead time variability can be meaningfully assessed.

Each item is plotted based on two dimensions: average repair duration (x-axis) and standard deviation of duration (y-axis). Visual cues are applied to support interpretation: discontinued items are highlighted in purple, and items that appear across both P64 and P65 repair types are highlighted in yellow. All other items are marked using the blue color.

Each plot is divided into four quadrants using a horizontal and vertical reference line to segment and interpret the scatter plot results more systematically. The vertical threshold is fixed at the ROLT target of 51 days, differentiating items that exceed the KPI from those that do not. For the horizontal axis, the threshold for "high variability" is determined using the 75th percentile of the standard deviation values among the visualized items. This choice balances outlier sensitivity and interpretability more effectively than the alternative of using the mean plus one standard deviation, which yielded significantly higher and less representative cutoffs, particularly for P64 items.

For P64, the 75th percentile of standard deviation is 28.7 days, while the mean plus standard deviation (based on population standard deviation) is 42.5 days. Given that the 75th percentile more closely reflects the upper quartile of the data distribution and avoids being skewed by a few extreme values, it is chosen as the horizontal cutoff. The 75th percentile threshold is also applied for P65, which resulted in a cutoff of 11.25 days to maintain consistency and interpretative clarity across P64 and P65 analyses.

This quadrant-based segmentation supports clearer prioritization. Items in the top-right quadrant (above the 75th percentile in variability and beyond the 51-day duration target) indicate both long and variable repair durations. The bottom-right quadrant represents the biggest concern since it identifies items with consistently long durations. Thus, suggesting structural process inefficiencies. The top-left quadrant highlights items with short average durations but high variability, warranting attention due to unpredictability. The bottom-left quadrant includes items with low duration and low variability, indicating efficient and stable repairs.

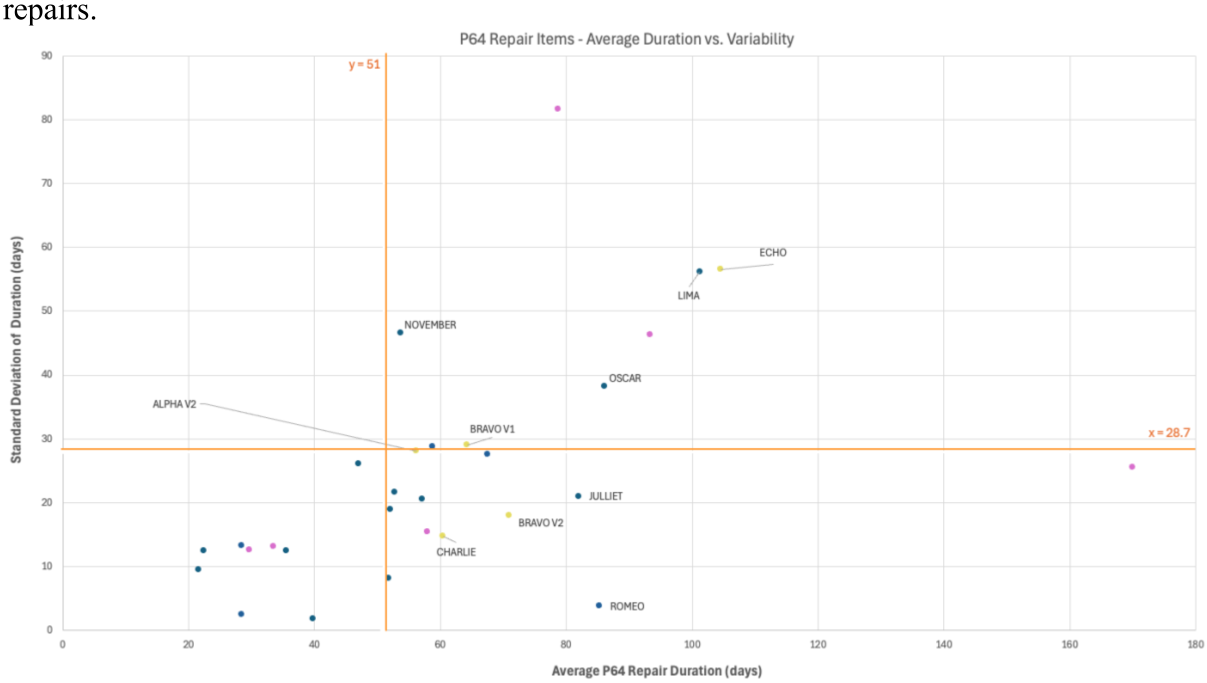

Figure 4.6: P64 Repair Items – Average Duration vs. Variability Scatter Plot

Bottom Right Quadrant: High Duration, Low Variability (Consistent Bottlenecks)
Twelve items fall within this quadrant, with two more positioned precisely on the threshold boundaries. Two of these are discontinued items (purple), while the rest are active or common items. *INDIA* appears to be the most problematic item based on its position. However, further inspection reveals it only occurred three times in 2024, limiting its systemic significance. Similarly, JULLIET which is also located in the same quadrant, had only two P64 occurrences.

In contrast, CHARLIE, which appears firmly within the bottom-right quadrant, has 5 P64 and 8 P65 repair orders, indicating recurring inefficiencies across both repair types. A similar pattern is observed with both versions of items *BRAVO::* **V2** is fully within the quadrant, with 2 P64 and 11 P65 orders and **V1** lies exactly on the variability threshold and also has 4 P64 and 1 P65 orders.

Lastly, *ALPHA V2*, has the highest frequency with 18 P64 and 16 P65 orders. Thus, making it one of the most critical candidates for deeper analysis and possible process intervention.

Top Right Quadrant: High Duration, High Variability (Irregular but Delayed)
Eight items are plotted in this quadrant, two of which are discontinued and two shared across repair types. As previously discussed, *BRAVO V1* straddles this boundary, but its consistent delay patterns make it analytically relevant.

Another noteworthy case is ECHO, which exhibits both high average duration and high variability. However, it only occurred twice in P64 and once in P65 in 2024, meaning its performance trend lacks statistical robustness.

Bottom Left Quadrant: Low Duration, Low Variability (Efficient *and Stable*)
Nine items fall in this quadrant. These repairs are consistently completed within the 51-day window and show low standard deviation, indicating either process efficiency or limited repair frequency. These items represent the benchmark or baseline for expected repair behavior.

Top Left Quadrant: Low Duration, High Variability (*Unstable but Fast*)
No items are positioned in this quadrant. This absence suggests that items with short average durations do not show erratic lead time behavior, reinforcing that high variability is often associated with longer delays.

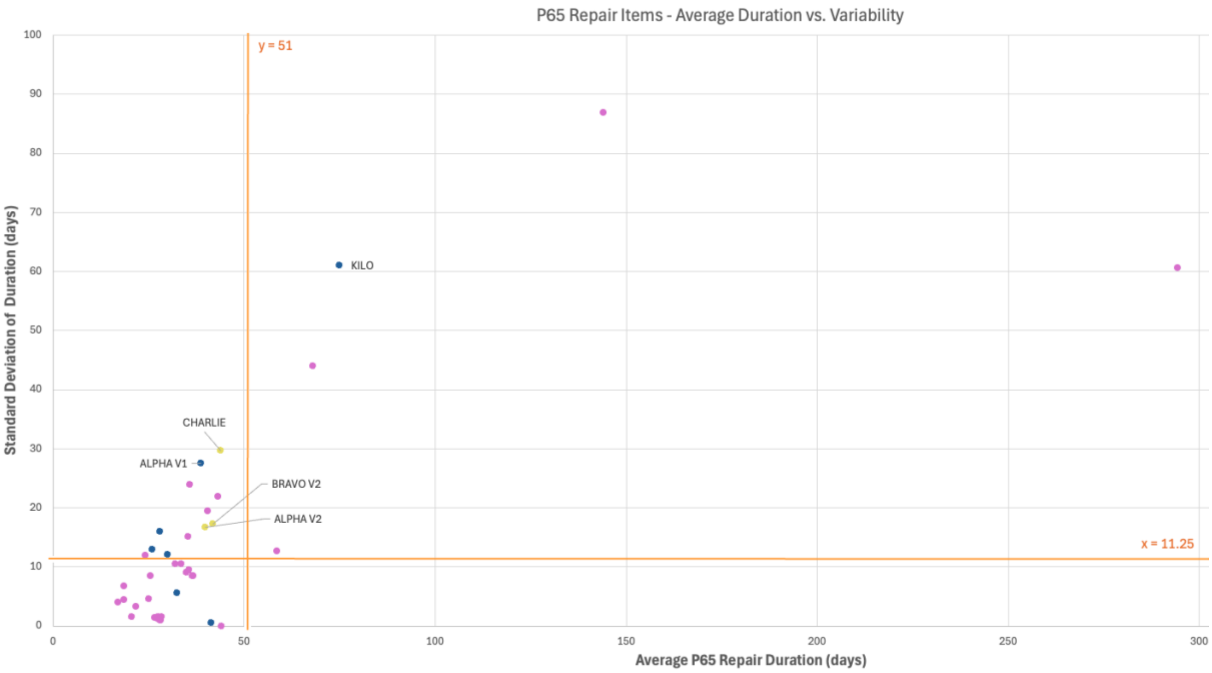

Figure 4.7: P65 Repair Items – Average Duration vs. Variability Scatter Plot

Top Right Quadrant: High Duration, High Variability (Irregular and Delayed)
This quadrant is primarily populated by discontinued items (purple), indicating that irregular and prolonged repair times are mostly associated with items being phased out. The only active item in this quadrant is *KILO*. However, it only had two P65 repair orders in 2024, so its strategic relevance remains limited. While these outliers may appear problematic, their low frequency weakens their significance from a systemic perspective.

Bottom Left Quadrant: Low Duration, Low Variability (Efficient and Stable)
25 of the 42 P65 items fall into this quadrant. This strong clustering indicates that the majority of P65 repairs are consistently completed within the 51-day KPI target and show low process variation. Compared to the P64 data, this quadrant is more densely populated, reinforcing earlier findings that P65 repairs perform significantly better overall due to going through one less step.

Top Left Quadrant: Low Duration, High Variability (Unstable but Fast)
Unlike the P64 analysis, the P65 scatter plot contains several items in this quadrant. These items are typically completed on time but exhibit inconsistent repair durations. Notably, the recurring active items highlighted in yellow appear: *CHARLIE, BRAVO V2, ALPHA V2, and ALPHA V1*. These items average below 51 days but show moderate to high variability, suggesting possible unstable processes that may require better standardization. Another possible reason for their position is that a few extreme outliers may increase the average value. Hence, it is important to see how many repair orders exceed 51 days for each item.

Bottom Right Quadrant: High Duration, Low Variability (Consistent Bottlenecks)
No items appear in this quadrant. This suggests the absence of systematic or recurring bottlenecks among P65 repairs. This sharply contrasts with the P64 scatter plot, where several active items did fall into this quadrant.

The quadrant-based scatter plots offer valuable insight into duration patterns and variability across repair items. However, they do not fully reflect the broader operational impact of each item. Specifically, items with extreme averages may appear problematic despite having very few occurrences. On the other hand, frequently delayed items with moderate averages may be underrepresented. The following section introduces a frequency-weighted Pareto analysis to address this limitation. This method calculates the total impact of each item as the product of its average duration and the number of repair orders. As a result, presenting a more comprehensive prioritization of high-impact items across both P64 and P65 repairs. This frequency-adjusted approach ensures that the items selected for deeper analysis and improvement efforts represent the most significant contributors to overall lead time delays.

4.5. Pareto-Based Bottleneck Prioritization

The previous section highlights items with long and variable durations. However, it does not factor in how frequently each item occurs, which is an essential consideration when evaluating their overall impact of items on the repair process. The current section applies a frequency-weighted Pareto analysis to address this. This method multiplies average duration by repair frequency:

$$Total\ Impact = Average\ Duration \times Frequency$$

Equation 4.1: Formula for Calculating Total Repair Impact

This method, reviewed in **Chapter 3**, where relevant literature demonstrated its effectiveness in prioritizing operational bottlenecks based on cumulative impact. This ensures that improvement efforts target the most operationally significant items across both P64 and P65 repair orders.

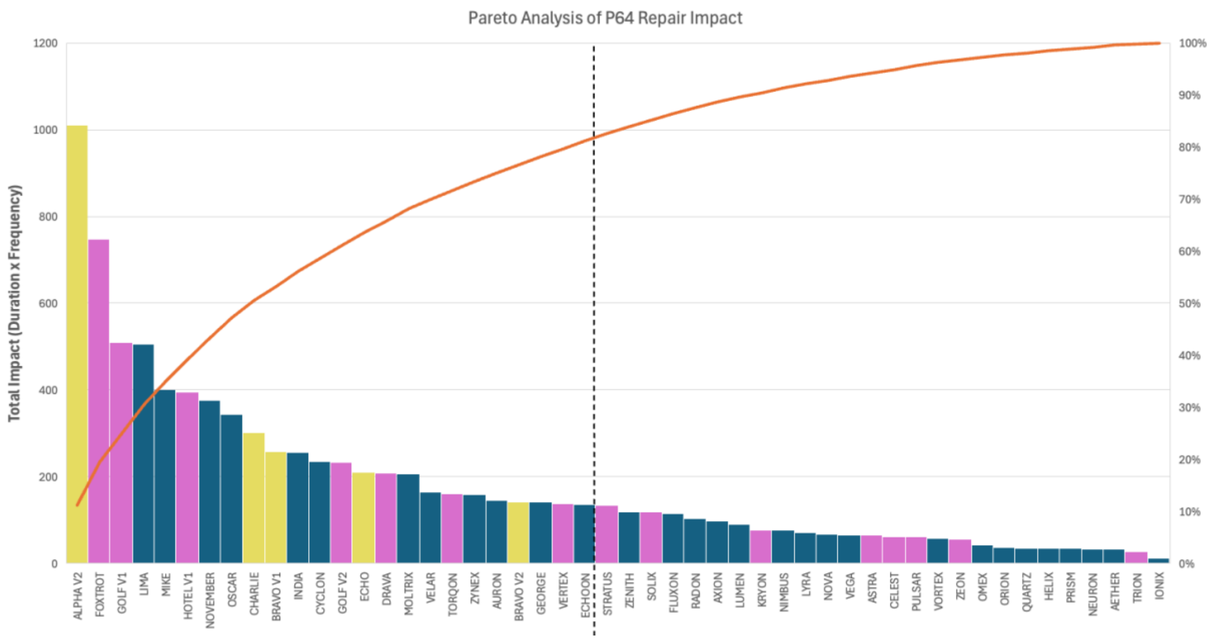

Figure 4.8: Pareto Chart of Total Impact for P64 Repair Items

A total of 50 fully documented P64 items are analyzed in the Pareto Chart presented in Figure 4.8. The analysis reveals that the top 24 items, 48% of P64 items, account for **81.1%** of the total impact, as marked by the dotted line. This confirms a classic Pareto distribution, where a concentrated set of items accounts for the majority of delays.

A color-coding scheme was applied to support traceability across this section: discontinued items are marked in purple, active items that appear in both P64 and P65 repairs are marked in yellow, and remaining active items unique to P64 or P65 are marked in blue. Notably, all five common items (yellow) identified earlier appear among the top contributors in this 80% high-impact zone. Together, they account for **21.1%** of the total impact, suggesting their recurring influence across repair flows. These shared items, along with several high-ranking active ones, warrant closer attention.

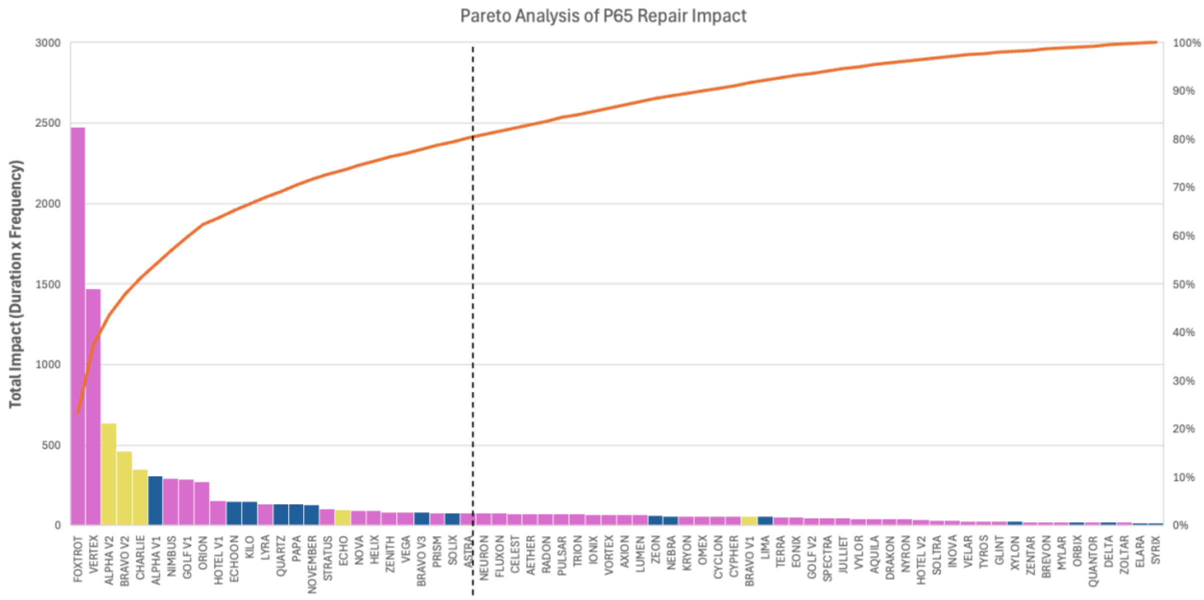

Figure 4.9: Pareto Chart of Total Impact for P65 Repair Items

A total of 70 documented P65 items are included in the Pareto analysis illustrated in Figure 4.9. The results reveal that the top 26 items, 37.1% of P65 items, collectively account for approximately 80% of the total repair impact, as marked by the dotted line on the chart.

A clear pattern emerges regarding item status: out of the 70 items analyzed, 46 are discontinued (represented in purple). Among the top 26 contributors, 14 are discontinued items. These 14 discontinued items alone account for 54.35% of the total repair impact. Thus, underscoring the need for careful prioritization to ensure that process improvement efforts are directed toward relevant and recurring issues rather than items being phased out.

Despite the dominance of discontinued items, four of the five previously identified high-impact common items (highlighted in yellow) again appear in this critical segment. Their reappearance reinforces their cross-category relevance. The four recurring common items account for 14.7% of the total impact within P65 repairs. The remaining eight active items in the 80% group contribute just 11.17%**,** highlighting the disproportionate influence of the recurring components. As with the P64 analysis, the purpose of this prioritization is not to declare definitive bottlenecks but rather to refine the scope of analysis. These selected items now serve as focal points for a more granular investigation into step-level process inefficiencies in the upcoming sections.

A filtered summary table (Table 4.2) is created to further refine the results. This table is filtered by total impact from largest to smallest, showing the active items from both analyses. Table 4.2 excludes discontinued parts. This targeted view aligns with NTS Hengelo's stated intention to focus improvement efforts on current, high-impact components.

Highest P64 Repair Items by Total Impact					
Item Key	Avg Duration	Frequency	Total Impact	Std Dev	Repair Type
ALPHA V2	56,16	18	1011	28,04	P64 & P65
LIMA	101,2	5	506	56,18	P64
MIKE	57,14	7	400	20,65	P64
NOVEMBER	53,71	7	376	46,65	P64
OSCAR	86	4	344	38,32	P64
CHARLIE	60,4	5	302	14,79	P64 & P65
BRAVO V1	64,25	4	257	29	P64 & P65
ECHO	104,5	2	209	56,5	P64 & P65
BRAVO V2	71	2	142	18	P64 & P65

Highest P65 Repair Items by Total Impact					
Item Key	Avg Duration	Frequency	Total Impact	Std Dev	Repair Type
ALPHA V2	39,75	16	636	16,74	P64 & P65
BRAVO V2	41,81	11	460	17,24	P64 & P65
CHARLIE	43,88	8	351	29,76	P64 & P65
ALPHA V1	38,75	8	310	27,54	P65
QUEBEC	76	2	152	0	P65
KILO	75	2	150	61	P65
ECHO	97	1	97	0	P64 & P65

Table 4.2: Highest Impact P64 and P65 Repair Items Based on Total Impact (Active Items Only)

Interestingly, four out of the 5 common active items appear in both top-impact lists. Notably, despite their frequency, these items show differences in ROLT compliance across repair types. As established in **Section 4.3**, approximately 81% of P65 repairs for Company X fall within the ROLT target, compared to only 48% for P64. Supporting the table that these shared components are often compliant in P65 repairs and non-compliant in P64 repairs. P65 repair orders are shorter due to the fact that its process flow has one less step than the P65 repair flow. However, it is important that even though the common items are compliant in P65 repairs, the 3 common items with the highest impact exceed the standard deviation threshold of 11.625 explained in the previous section, so this unpredictability factor raises concerns. On the other hand, the common item *ECHO* which was in the top right quadrant in the scatter plot and seemed to raise concerns, it has a std dev of 0 since it has only 1 occurrence the same goes to the 5th and 6th item in the P65 summairzed table thus leaving the first 4 items as the possible focus. This is further supported in the P64 summarized table, with the delays in these common items and the 4 other active items specific to P64 may also pose as a threat. The divergence in P64 and P65 results underscores the variability in performance depending on the repair context and further highlights the need to examine item-specific behavior in both categories.

Moreover, while several items with long durations also appear in the scatter plots, many of them are infrequent and exclusive to one repair type. These outliers may overstate their importance when frequency is ignored. Thus, this Pareto-based approach more effectively filters out such anomalies and reinforces the importance of high-frequency, high-impact items, aligning directly with stakeholder priorities at NTS Hengelo.

The next section examines the deviation between planned and actual lead times, alongside the efficiency percentage of each item to reinforce and validate these findings,. This additional lens supports a more nuanced understanding of performance gaps. Together, these metrics enable a final, evidence-based selection of candidates for the step-level bottleneck analysis in Section 4.7.

4.6. Lead Time Deviation and Efficiency Analysis

4.6.1. Lead Time Deviation Analysis

This section builds upon the previous analyses by investigating how actual lead times deviate from planned expectations. Deviations are segmented into productive and non-productive components to gain detailed insight into systemic inefficiencies. For each completed repair order, these deviations are calculated by subtracting the planned duration (from the Enterprise Resource Planning (ERP) system) from the actual recorded duration, and the results are visualized using box plots for P64 and P65 repairs (Figure 4.10).

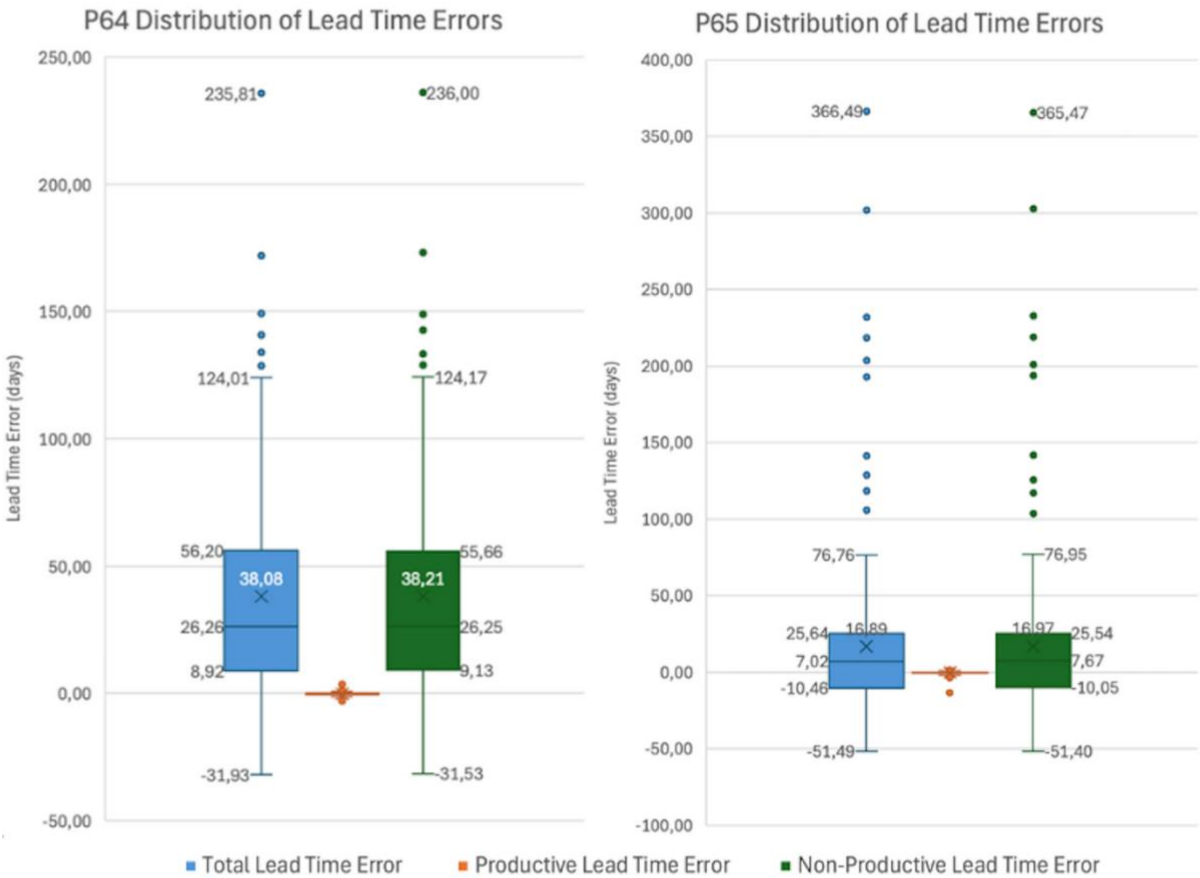

Figure 4.10: Box Plot Analysis of Lead Time Deviations for P64 and P65 Repairs

The box plots reveal several important trends. First, the total lead time error shows a wide spread for both P64 and P65 repairs, showing several outliers extending far beyond the upper quartiles. For P64 repairs, the mean deviation in total duration is **38.08 days**. As for P65 repairs, it is less than half at **16.89 days**. These delays indicate substantial variance from what was originally planned, especially in complaint-driven repairs (P64).

More notably, the largest share of this deviation stems from non-productive time. For P64 orders, the average non-productive deviation is **38.21 days**, while for P65 it is **16.97 days**. On the other hand, the productive time component remains relatively stable having a narrow range of values clustered around zero for both repair types. This suggests that when technicians are actively working on items, durations closely match planned expectations. However, delays accumulate heavily during idle periods such as waiting for coordination, approvals, or parts.

It is also worth noting that the average non-productive deviation slightly exceeds the total deviation in some cases. This is due to the fact that productive time deviations are sometimes negative, meaning that productive tasks are completed faster than planned. As a result, there is a partial offset to the longer-than-expected non-productive delays.

These findings imply two critical issues: (1) a systemic underestimation or mismanagement of non-productive phases in the planning process, and (2) potential inconsistencies in how non-productive activities are logged in the ERP system. The data point to flawed assumptions in planning or gaps in operational execution since 96% of the deviation in P64 repairs and over 92% in P65 repairs are attributable to non-productive time.

4.6.2. Efficiency Analysis

This section builds on the deviation analysis by assessing the operational efficiency of repair activities. Efficiency reflects the proportion of time spent on actual value-adding tasks versus total lead time. This metric is critical in identifying underutilized periods and systemic idle times across repair orders.

$$Efficiency = \frac{Actual\ Productive\ Time}{(Actual\ Productive\ Time + Actual\ Non - Productive\ Time)} \times 100\%$$

Equation 4.2: Formula for Calculating Operational Efficiency of Repair Orders

Figures 4.11 and 4.12 visualize the active P64 and P65 items with the highest weighted lead time deviations, along with their respective efficiency percentages. In the charts, the bars represent the weighted lead time deviation per item, while the orange line plots the corresponding average efficiency percentage.

In the case of **P64**, the highest average item efficiency was **8.06%**, with a total average of just **1.52%**. To put this into perspective: if a P64 repair took 50 days and its efficiency is 1.52%, this implies that only 0.76 days (≈18.24 hours) are spent on productive work, while the rest is idle or administrative. This stark contrast reinforces the presence of systemic inefficiencies, where prolonged lead times are not matched by proportional productive effort.

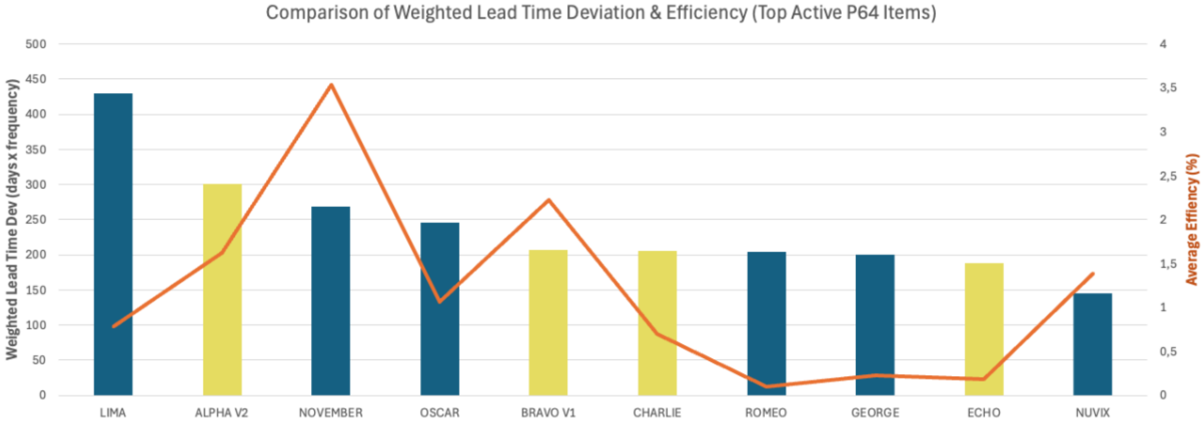

Figure 4.11: Weighted Lead Time Deviation and Efficiency of Top Active P64 Repair Items

Among the top active P64 items, several notable trends emerge. Four of the five common items between P64 and P65 (highlighted in yellow) consistently reappear as high-deviation, low-efficiency candidates. In particular, LIMA and *NOVEMBER***,** though unique to P64, stand out across multiple analyses. Moreover, both appeared prominently in the scatter plots and Pareto charts. Their medium-level frequencies (5 and 7 occurrences, respectively) and average durations exceeding the 51-day ROLT threshold (101.2 and 53.71 days) reinforce their classification as strong bottleneck candidates. These results illustrate the added value of the efficiency metric in validating earlier findings and highlighting items with chronically poor time utilization.

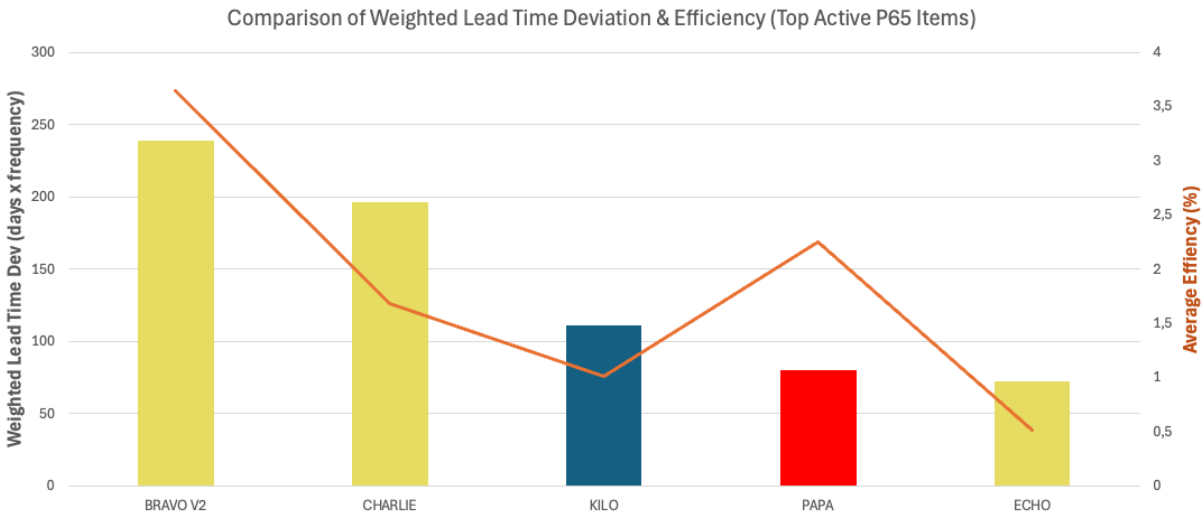

Figure 4.12: Weighted Lead Time Deviation and Efficiency of Top Active P65 Repair Items

In contrast to P64, the average efficiency across all active P65 items is 4.96%, which is notably higher. However, this average is inflated by a small number of items with limited frequency (one or two repair orders) that reported unusually high efficiency scores of 25%, 27%, and even 70%. These outliers distort the mean and reduce its representativeness for broader conclusions.

Three of the five common items between P64 and P65 (highlighted in yellow) reappear in this analysis. Thus, reinforcing their consistent performance issues across both repair types. One item, *ECHO*, has only a single recorded repair in 2024. This limits its importance despite its high deviation, as frequency-weighted insights favor items with recurring inefficiencies.

A particularly interesting case is PAPA, which appears as a top deviation item despite having a negative weighted deviation score of –80.26 days. This suggests a significant overestimation in planning. For visual consistency and to support cross-comparison, the absolute value is used in the figure. Although unique to P65, its medium repair frequency (five occurrences) and strong deviation suggest it may still warrant closer investigation in the step-level analysis.

These findings not only validate earlier Pareto and variability results but also emphasize the role of planning accuracy in driving repair inefficiencies. This analysis enables convergence on a refined and evidence-based shortlist of candidates for the next step: step-level bottleneck analysis.

4.7. Step-Level Bottleneck Analysis

4.7.1. Selection of Focus Items

In the previous sections, various repair items are analyzed using multiple quantitative techniques, including variability analysis, Pareto impact assessment, and lead time deviation and efficiency evaluation. It is necessary to consolidate these findings and determine which specific items warrant detailed investigation at the process step level to transition into step-level analysis.

Item Key	Frequency Across P64 & P65	Late Occurences	Lead Time Deviation (days)	Avg Eff (%)	*Repair Type*
ECHO	3	2	86,73	0,35	P64 & P65
ALPHA V1	8	2	1,65	2,10	P65
ALPHA V2	34	14	7,93	1,80	P64 & P65
BRAVO V1	5	4	48,85	1,97	P64 & P65
BRAVO V2	13	6	26,54	3,40	P64 & P65
CHARLIE	13	5	30,91	1,35	P64 & P65
BRAVO V3	2	0	15,22	1,51	*P65*
KILO	2	1	55,66	1,01	*P65*
NOVEMBER	12	3	33,20	2,92	*P64*
LIMA	5	5	86,07	0,79	*P64*
PAPA	5	0	-80,26	2,25	*P65*
ROMEO	3	3	68,28	0,10	*P64*
JULLIET	3	2	41,86	0,33	*P64*

Table 4.3: Consolidated Performance Summary of Key Repair Items Across P64 and P65 Orders

Table 4.3 above summarizes thirteen repair items that consistently appeared across multiple analyses. This table aggregates performance across both types to present a unified view, unlike the earlier sections that treated P64 and P65 repair orders separately. Moreover, it includes the total frequency, number of late occurrences (repairs exceeding the 51-day ROLT threshold), lead time deviation, and average efficiency per item.

In line with the two-phase analytical framework introduced in Section 4.1, a second round of stakeholder interviews is conducted following the core data analyses. Importantly, findings are not shared directly to avoid response bias. The repair coordinator independently identified four items as persistently problematic: *BRAVO V1* and *BRAVO V2, CHARLIE,* and *ALPHA V2*. He explained that these items were consistently causing delays due to their high repair frequency and their presence across both P64 and P65 workflows.

Interestingly, this qualitative input closely aligns with the data. For instance, *ALPHA V2* registered 34 repairs in 2024. Of the 34 repair orders, 14 exceeded the ROLT threshold. While ALPHA V2 showed signs of delay, ALPHA V1 which is a version lower, has a significantly higher historical frequency (159 total repair orders from 2022-2023). Hence, in the first quarter of 2024, it underwent process standardization through the introduction of fixed pricing. This measure, implemented due to its high volume and long lead times, aimed to reduce administrative delays and streamline processing. In 2024, there were 8 fully documented repair orders for this item, with only 2 exceeding the 51-day ROLT threshold. Given this positive performance following the improvement, ALPHA V1 is not included in the step-level bottleneck analysis. However, it serves as a benchmark, helping to illustrate the potential impact of reducing administrative delays and simplifying recurring workflows.

This outcome supports earlier findings in **Section 4.6.2**, where average efficiency rates were very low. The results showed an average efficiency of 1.52% for P64 items and 4.96% for P65 items. This confirms that excessive time is being lost in administrative and logistic steps, rather than in actual repair work.

This benchmark informs the selection of other items that exhibit: (1) recurrence across both repair types, (2) low efficiency, and (3) substantial lead time deviation. Based on this, four items are prioritized: *ALPHA V2*, *BRAVO V1 and V2****,*** *and CHARLIE*. In addition, the following are included due to forward-looking stakeholder insights:

- *BRAVO V3*: Only two repair orders were registered in 2024. However, Company X explicitly identified it as a successor to V1 and V2. The repair coordinator highlighted that NTS Hengelo that there will be an increase in repair volume in 2025.
- *DELTA* – It is not highlighted in any of the analyses done since it appeared only once in 2024 (and was completed on time). However, it is also flagged by NTS Hengelo for expected growth in future repair frequency.

On the other hand, six items are deliberately excluded:

- *ECHO*, *KILO*, and *JULLIET*: All show low frequency (2–3 orders) with no anticipated increase.
- *NOVEMBER* – Despite 12 occurrences, only three are late, and the item's lead time and efficiency metrics are not severe.
- *PAPA* – Although it has a large negative deviation, all five cases are completed on time. This item typically uses half of the allotted duration.
- *LIMA and ROMEO*: Both have 100% lateness, but are removed due to missing step-level data. Of the 8 orders, only one has valid timestamps.

As a result, the following six items are chosen for step-level mapping and analysis:

1. ALPHA V2
2. BRAVO V1
3. BRAVO V2
4. CHARLIE
5. BRAVO V3
6. DELTA

These items are examined in Section 4.7.2 through step-level process mapping to identify where delays accumulate, which steps exhibit the highest variation, and how inefficiencies can be reduced through targeted interventions.

4.7.2. Mapping Time Allocation and Identifying Step-Level Inefficiencies

After selecting the seven focus items based on quantitative analyses and stakeholder input from both NTS Hengelo and Company X, this section investigates the step-level performance of each repair item. A deep dive is conducted into each repair order using ERP timestamps and recorded durations. Also, the time distributed across the standard seven process steps is analyzed:

1. Formulating Plan
2. Quality Complaint Assessment *(P64 orders only)*
3. Cleanroom Analysis
4. Planning & Logistics
5. Sales Communication to Customer
6. Cleanroom Execution
7. Final Cleanroom Inspection

Only completed and properly documented repair orders are included to ensure data integrity. Some orders have lead time data logged only for a single step (rendering them invalid for analysis), thus these are excluded. However, repair orders from late 2023 into 2024 or early 2025 are retained for this section to increase the number of usable cases, especially for items with low volumes like *DELTA*. The number of valid repair orders per item is as follows:

- ALPHA V2: 30
- BRAVO V1: 4
- BRAVO V2: 14
- CHARLIE: 16
- BRAVO V3: 4
- DELTA: 1

Individual pie charts are generated for each item to visualize time distribution across the process steps in Figure 4.13. The seven standardized repair process steps listed above serve as the foundation for this step-level analysis. Each of these stages which range from planning and cleanroom analysis to final inspection has been mapped against ERP-recorded durations to visualize their relative time consumption. These stages are directly reflected in the pie charts below, which break down total lead time per item by step. Thus, allowing for the immediate identification of which process stages absorb the most time.

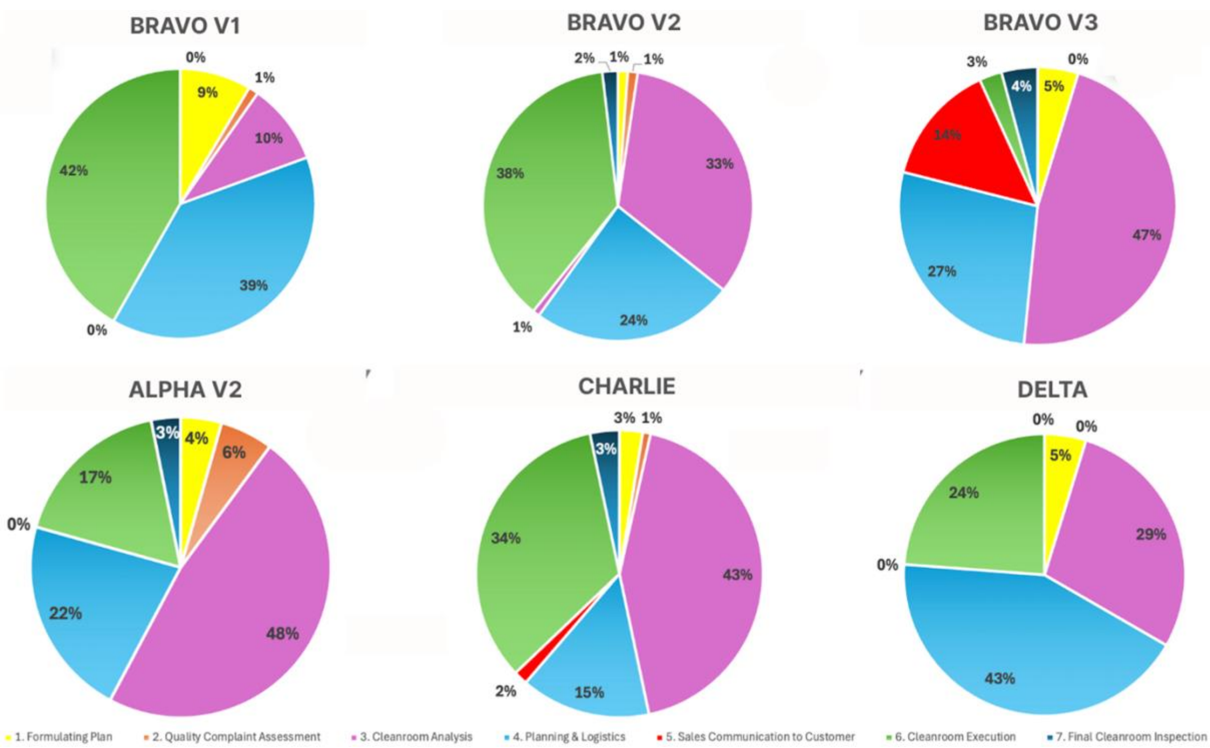

Figure 4.13: Average Time Distribution Across Process Steps for Selected Repair Items

Across most items, three steps consistently account for the majority of total lead time:

- **Step 3: Cleanroom Analysis**: This step often shows extended durations, particularly for P64 repairs. Even though a portion of this time may be due to root cause assessment requirements, further analysis is needed to determine whether delays are technical, related to queuing, or procedural.
- **Step 4: Planning & Logistics**: This consistently high-duration step may reflect the complexity of routing approvals and coordination tasks. Though the exact breakdown of sub-tasks is not logged in the ERP system, the persistence of long durations across all items suggests a structural inefficiency within the support flow.
- **Step 6: Cleanroom Execution**: As the core technical phase, this step naturally requires time, but the extent of its duration varies. This step will be further examined using stacked bar charts that distinguish between productive and non-productive time to determine whether long execution times are the result of technical complexity or caused by external factors like queuing or miscoordination.

For some items, such as *BRAVO V3*, Step 5 (Sales Communication to Customer) consumes time, suggesting variability in administrative delay patterns across items. This step-level disaggregation enables a precise diagnosis of inefficiencies that may not be visible at the aggregate item level.

Figure 4.14 presents stacked bar charts that further disaggregate the total duration into productive (orange) and unproductive (blue) components. These stacked bar charts complement the pie charts by showing the distribution of time across process steps. Moreover, they offer a clearer view of where inefficiencies originate and how they manifest across each item.

Figure 4.14: Stacked Bar Chart of Productive vs. Unproductive Time per Process Step for Selected Items

Notably, unproductive time dominates all steps across the analyzed items. However, the longest unproductive durations are consistently observed in Step 3 (Cleanroom Analysis)**,** Step 4 (Planning & Logistics)**,** and Step 6 (Cleanroom Execution)**.** This is largely a result of these steps spanning longer total durations, as shown in the earlier pie charts. Supporting steps, such as Sales Communication or Formulation Planning, are also unproductive. However, the three core stages accumulate significant idle time likely due to process queuing, excessive steps, or administrative loops.

This reinforces earlier findings from **Chapter 2** and **Section 4.6**, which identified these intermediate stages as systemic bottlenecks likely driven by queuing, excessive administrative steps, and coordination delays. Importantly, only productive time is billable to Company X. Thus, prolonged unproductive durations represent hidden costs and missed performance opportunities. Note, DELTA is excluded from Figures 4.14 and 4.15 due to having only one documented occurrence. This limits the reliability of any generalizations based on that data point.

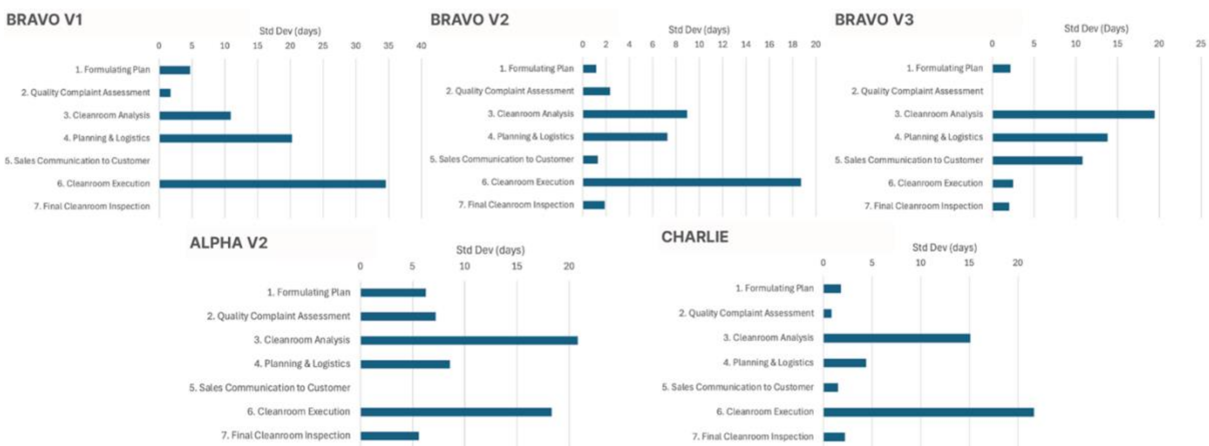

Figure 4.15: Standard Deviation of Unproductive Time per Process Step for Selected Repair Items

Figure 4.15 presents the standard deviation of unproductive time per step for each of the five selected repair items. The visualizations aim to better understand how consistently time is being lost across process steps. Figure 4.14 illustrates where the majority of time is spent. Now, Figure 4.15 adds another layer by showing the variability of unproductive durations. Thus, revealing which steps are subject to irregular delays versus those that are consistently problematic.

The results reveal two key insights. First, Step 4: Planning & Logistics consistently shows low standard deviation across 4 of the 5 items. Thus, indicating that the delays in this step are systematically recurring rather than sporadic. This aligns with earlier observations that this step involves complex administrative handovers, approvals, and coordination activities that regularly prolong repair times.

Second, Step 3: Cleanroom Analysis and Step 6: Cleanroom Execution exhibit relatively high variability in unproductive time. This suggests that while these steps contribute heavily to total delays, the extent of delay fluctuates significantly between repair orders. Such variability may stem from case-specific factors such as item complexity, technician availability, or queuing behind new builds in the cleanroom.

These findings reinforce that Step 4 is a structurally embedded bottleneck. On the other hand, Steps 3 and 6 appear to suffer from less predictable, case-by-case inefficiencies despite their high contribution to total duration.

A cumulative Pareto analysis, Figure 4.16, is presented to further quantify where the most unproductive time is lost by aggregating the total unproductive durations per process step across all seven selected items. This approach builds on the item-level stacked bar and variability analyses and enables a system-wide view of inefficiency by highlighting which operational steps consistently contribute most to idle time.

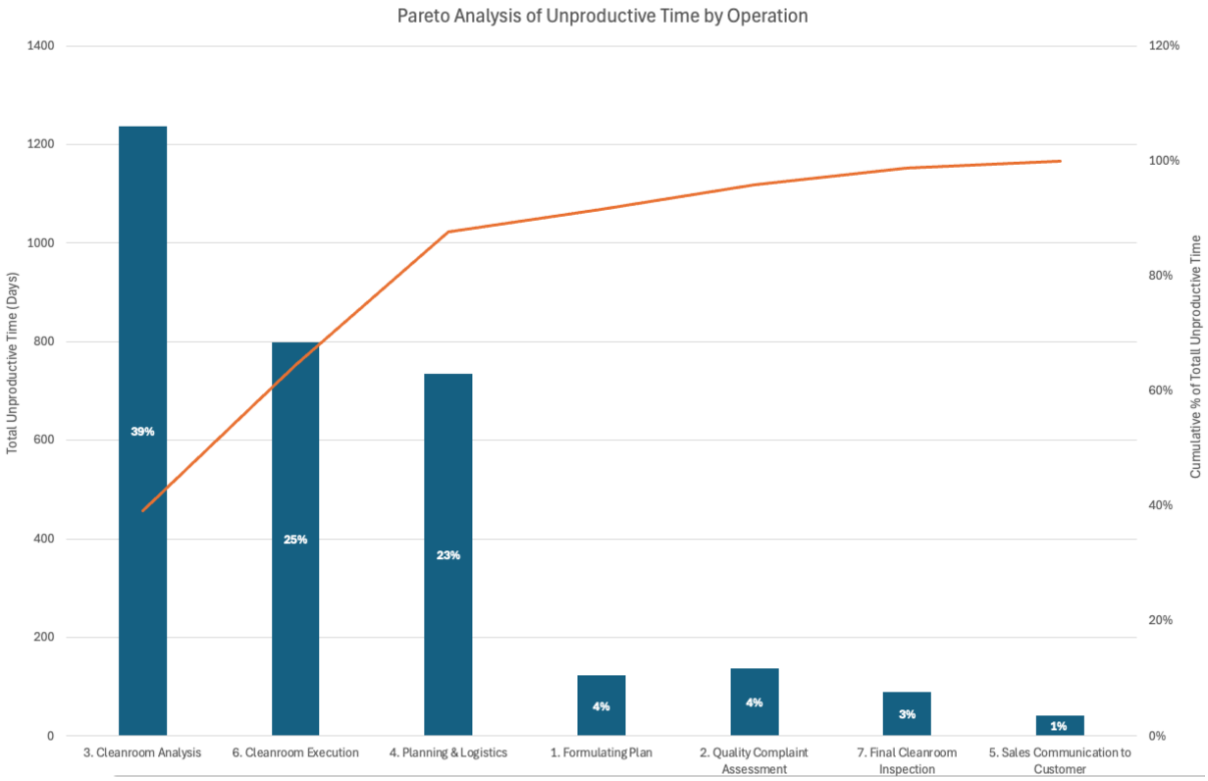

Figure 4.16: Pareto Chart of Total Unproductive Time by Repair Step (All six Items Combined)

As shown in Figure 4.16, the findings are conclusive: Step 3 (Cleanroom Analysis), Step 6 (Cleanroom Execution), and Step 4 (Planning & Logistics) collectively account for approximately 87% of all unproductive time. This supports earlier observations from pie and stacked bar charts and confirms that these three stages are the dominant contributors to prolonged repair lead times.

The impact of these steps is not merely quantitative. During stakeholder interviews, the respondents independently cited Steps 3 through 6 as the most delay-prone parts of the process without prior exposure to the results. As one cleanroom planner stated, *"The more steps there are, the more complexity and time are added."* This convergence between empirical data and frontline experience strengthens the credibility of the findings and points to clear areas for intervention.

At the same time, this analysis reveals potential issues in ERP time logging accuracy. More specifically, in Step 1 (Formulating Plan) and Step 5 (Sales Communication to Customer), which frequently display implausibly low durations. These discrepancies suggest underreporting or inconsistent logging practices that limit full visibility into where time is being spent. Chapters 6 and 7 reflect on these data quality concerns and discuss recommendations for improving the reliability of system inputs.

In summary, Chapter 4 has narrowed down six critical repair items for targeted improvement. ALPHA V1 is not targeted for new interventions, as it has already undergone process standardization through the introduction of fixed pricing. This reform, implemented due to the item's historically high frequency and lead times, aimed to streamline administrative steps and reduce delays. The effectiveness of this intervention is looked at in the next chapter by analyzing its 2025 repair data in greater detail, offering insight into the potential value of applying similar measures to the remaining items. These findings lay the foundation for Chapter 5, which proposes practical solutions to reducing friction in administrative handovers. Aiming to help NTS Hengelo improve repair efficiency and move closer to consistently achieving the 90% ROLT compliance target.

5. Addressing the Identified Bottlenecks

This chapter responds to core Sub-Question 4: *"What are the solutions to address the identified bottlenecks in NTS Hengelo's repair process?"* by translating the key findings from **Chapter 4** into applicable solutions. Section 5.1 addresses *Sub-Question 4.1: "What structured methods can be utilized to resolve bottlenecks and improve the operational performance of NTS Hengelo?"* by introducing three structured theoretical approaches that provide frameworks for resolving administrative delays and inefficiencies in the repair workflow.

Section 5.2 builds on this foundation by identifying four practical tools tailored to NTS Hengelo's specific challenges, ending in a focused justification for the selection of fixed-cost pricing in Section 5.3. The remaining sections, 5.4 and 5.5, answer *Sub-Question 4.2: "Which of these resolution methods are most applicable to the context of NTS Hengelo's repair process?"* by applying this fixed-pricing framework to six recurring items and introducing a categorization flowchart that guides future pricing decisions. Together, these sections form a coherent and data-supported set of interventions designed to reduce quoting delays, improve process flow, and enhance ROLT performance.

5.1. Theoretical Approaches to Address Bottlenecks

Chapter 4 identified six recurring repair items at NTS Hengelo that consistently contribute to delayed repair orders or are expected to increase in frequency in upcoming stages, thus disproportionately impacting the ROLT KPI. Step-level analyses of these items reveal that a significant portion of process time is consumed by unproductive administrative activities. More specifically, during the quotation and coordination stages. These delays are largely caused by repetitive approvals and excessive manual communication loops. This section presents relevant theoretical approaches aiming at reducing excessive administrative steps and standardizing process flow in repair environments to improve operational efficiency and ensure faster repair throughput.

5.1.1. Lean Thinking

Lean Thinking is a process improvement philosophy that emphasizes the elimination of waste and the creation of efficient workflows that bring value (Hines et al., 2004). Originally developed within manufacturing, Lean has been successfully adapted to administrative and service-based environments, where inefficiencies often stem from non-standardized procedures, repetitive handoffs, and poor information flow (Lobo-Prat et al., 2024).

In Lean, waste is categorized into eight types, including waiting, overprocessing, motion, defects, and underutilized human potential (Douglas et al., 2015). Several of these are highly relevant to administrative activities in repair environments. For example, unclear task ownership, lack of visual oversight, inconsistent communication routines, and redundant approvals can all lead to unnecessary delays and unproductive time.

A key Lean principle applicable to this context is Continuous Flow, which promotes uninterrupted progression through a process with minimal waiting or batching between steps (Poksinska, B., 2010). Continuous Flow can be used in information-based processes even though it is usually applied to the physical flow. In administrative repair environments, this means ensuring that activities such as quotation preparation, internal validation, and approval are executed in a smooth, predefined sequence. By minimizing delays between these steps, organizations can reduce lead time and avoid the fragmentation that often causes repair order backlogs (Melton, 2005).

Rather than serving as a prescriptive solution, Lean may be used as an overarching improvement approach. It provides both a mindset and a flexible toolbox to guide the reduction of administrative bottlenecks, while allowing for the integration of more specific tools and interventions based on local needs and stakeholder input (Melton, 2005).

5.1.2. Business Process Standardization

Business Process Standardization (BPS) refers to the practice of designing and implementing consistent procedures, rules, and structures to ensure predictable and efficient execution of routine tasks across an organization (Goel et al., 2023). It is particularly valuable in settings where frequent human intervention, communication gaps, or inconsistent decision-making contribute to process delays or variation in outcomes (Goel et al., 2023).
In administrative and service contexts, BPS aims to minimize ambiguity and reduce dependence on ad hoc coordination by clearly defining responsibilities, task sequences, and documentation requirements (Münstermann, 2010).

For NTS Hengelo’s repair environment, standardization provides a conceptual foundation for interventions such as defining clear communication protocols between departments, encouraging consistent documentation of repair hours, and guiding cleanroom workers through visual progress updates. Process execution becomes less reliant on individual interpretation and more robust against personnel changes or communication breakdowns by embedding repeatable standards into daily operations.

Importantly, BPS also facilitates monitoring and continuous improvement (Münstermann, 2010). When processes are executed consistently, deviations can be more easily detected, and corrective actions can be applied systematically (Münstermann, 2010). As a result, BPS plays a dual role in both reducing administrative inefficiencies and enabling long-term process control. Thus making it a highly relevant framework for addressing the coordination and documentation bottlenecks observed in NTS Hengelo’s repair processes.

5.1.3. Business Process Reengineering

Business Process Reengineering (BPR) is a management approach that involves the fundamental rethinking and radical redesign of business processes to achieve significant improvements in performance, efficiency, and responsiveness (Anand et al., 2013). Unlike incremental improvement frameworks such as Lean or Six Sigma, BPR focuses on breaking down existing processes and reconstructing them from the ground up to better meet organizational objectives (Anand et al., 2013).

Applied to administrative repair processes, BPR offers a structured approach for eliminating delays caused by outdated workflows, unclear responsibilities, and unclear prioritization. For example, the quotation process involves multiple approval loops and inconsistent documentation, which could theoretically be redesigned into a streamlined, automated system with clear checkpoints and fewer manual touchpoints. Similarly, cross-departmental handoffs between cleanroom workers, coordinators, and planners could be restructured into more centralized, digitally integrated routines.

BPR has been used effectively in large-scale service environments to gain drastic improvements (Anand et al., 2013). However, its success often depends on extensive organizational commitment, high levels of change readiness, and a willingness to accept short-term disruption in exchange for long-term gains.

5.1.4. Rationale for Method(s) Selection

In summary, this section has outlined three theoretical approaches that offer frameworks for addressing the administrative inefficiencies identified in NTS Hengelo’s repair process. Lean Thinking and Business Process Standardization (BPS) are both well-suited to localized, operational-level interventions. They support structured, incremental improvements that can be implemented without significant disruption, making them directly applicable to the recurring quotation and coordination issues currently affecting Repair Order Lead Time (ROLT) performance.

Business Process Reengineering (BPR), while highly valuable in its own right, is better positioned as a long-term strategic approach. As discussed, BPR offers the potential to redesign end-to-end workflows and eliminate structural inefficiencies across departments. However, the scope of this thesis is focused on solving a specific, quantifiable operational issue. More specifically, reducing administrative delays tied to six recurring repair items. These delays significantly impact ROLT compliance and can be addressed through targeted interventions within existing process boundaries.

That said, this operational solution alone is not sufficient to solve the broader problem. One critical underlying issue observed during this research is a general lack of awareness and commitment regarding the role and urgency of repairs. This organizational mindset has left repairs in a kind of "gray area," without the clear ownership or prioritization seen in new build processes. In that regard, once this thesis contributes to improving visibility and operational control, a broader process transformation led by BPR could be extremely valuable in the future. Such a redesign would be more feasible and impactful once organizational awareness and alignment around repair importance have matured. These broader organizational dimensions and long-term recommendations will be explored further in **Chapters 6 and 7**.

5.2. Practical Tools to Reduce Administrative Time

Based on the theoretical foundations outlined in **Section 5.1**, several practical tools are identified as potential interventions to reduce the excessive administrative time associated with NTS Hengelo’s repair process. These tools are not selected arbitrarily, but they emerge directly from stakeholder interviews and process data analysis. Key personnel involved in the repair process, such as the repair coordinator, cleanroom planner, sales representative, and planning coordinator, highlight specific pain points that consistently lead to delays, fragmentation, and inefficiencies. Additionally, the repair order data provides quantitative evidence of the misalignment between planned and actual process execution, reinforcing the qualitative findings.

Four recurring causes of administrative inefficiency are identified and translated into practical tools or intervention opportunities. Each is briefly presented below, along with the rationale, supporting stakeholder input, and a high-level assessment of its potential benefits and limitations.

5.2.1. Fixed-Cost Pricing

A recurring theme across stakeholder interviews is the time-consuming coordination required to confirm repair pricing with Company X. The current process involves multiple steps: after the cleanroom worker analyzes the item, the repair coordinator must confirm the expected hours and materials, the sales department then contacts Company X for approval, and only after the customer approves the quote can the cleanroom team begin the repair. According to the repair coordinator, cleanroom planner, and sales representative, this back-and-forth loop introduces substantial waiting time and creates administrative waste.

Quantitative repair order data confirms that these pricing-related delays are a critical bottleneck. In almost all cases, the physical repair time is significantly shorter than the time spent waiting for pricing approvals. Stakeholders emphasize that pre-defined, fixed-cost pricing for recurring items, such as those already implemented for ALPHA V1, could eliminate this delay entirely. However, the effectiveness of this tool depends on internal and external acceptance.

5.2.2. Visual Progress Tracking for Cleanroom Workers

Another challenge that is raised, particularly by the cleanroom planner, is the lack of visibility for cleanroom workers into the current progress of repair orders. Although repair plans are made, they are not consistently followed, often because these repairs are deprioritized in favor of new builds. As a result, even after pricing is approved, repair items may sit idle. A proposed solution is to introduce a visual dashboard or tracking aid to make the status of in-progress repairs more explicit and visible to cleanroom staff.

However, opinions are mixed. While the cleanroom planner supports the idea, the repair coordinator questioned its value, arguing that plans already exist and the issue lies more in priority enforcement than in a lack of visibility.

5.2.3. Awareness Training and Structured Communication

Multiple stakeholders in the repair process flow point to a deeper, systemic issue: a lack of awareness and internal commitment toward repairs. Repairs are often treated as secondary to new builds, not because of negligence, but due to an organizational mindset that views repairs as less urgent or important. This perception contributes to inconsistent communication, unclear ownership, and delays in execution.

However, this deprioritization is surprising considering that repairs are often more financially attractive than new builds, both for NTS Hengelo and for Company X. In addition, they align strongly with the growing sustainability ambitions of both companies. These dual benefits, financial and environmental, should be emphasized internally as part of awareness efforts to shift perception and elevate the strategic value of repairs.

A potential solution involves raising awareness and providing basic process training to clarify the importance of repair work, its impact on the company's KPIs (such as ROLT compliance), and the need for timely collaboration. This could be supported by structured communication or internal briefings to foster shared understanding across cleanroom, planning, and coordination roles.

5.2.4. Accurate Hour Logging in ERP System

Analysis of ERP timestamps reveals a disconnect between actual repair execution and recorded durations. In many cases, the data is incomplete or inconsistent, largely because key stakeholders fail to consistently log hours for repairs. This undermines process analysis, delays cost tracking, and makes continuous improvement difficult. When asked, stakeholders admitted that repairs are not prioritized. As a result, clocking hours is often neglected or postponed.

A potential tool to address this issue is the reinforcement of accurate hour logging practices through automated prompts within the ERP system, management follow-ups, or simple incentives. However, like the awareness challenge, this solution also depends on a cultural shift in how repairs are viewed internally.

5.3. Justification for Focus on Fixed-Cost Pricing

While all four tools proposed in Section 5.2 are important for tackling administrative inefficiencies, fixed-cost pricing is explored here in greater detail due to its immediate feasibility, quantifiable benefits, and alignment with both stakeholder concerns and available data. The remaining three interventions, visual tracking, awareness training, and ERP logging improvements, are equally critical to achieving the broader performance objective of consistently meeting the 90% ROLT KPI. These tools are revisited with concrete implementation steps in Chapters 6 and 7. Ultimately, no single intervention is sufficient on its own. Instead, this section demonstrates how fixed-cost pricing can act as an operational entry point, one that builds momentum while supporting and complementing the broader, organization-wide transformation needed.

The proposal to implement a visual progress tracking system for cleanroom workers presents potential value by improving transparency and making repair work more explicit. As suggested by the cleanroom planner, a visual aid could help clarify which repairs are active and encourage follow-through. However, this tool does not address the underlying issue repeatedly raised in stakeholder interviews: a lack of awareness and prioritization of repair orders among cleanroom staff. Without first establishing a cultural shift in how repairs are perceived, visual tools may have limited impact. This intervention may prove highly effective in the future, once a stronger sense of process ownership is established.

A similar rationale applies to the issue of incomplete or inaccurate hour logging in the ERP system. As detailed in Section 4.2, 18.2% of relevant repair data was lost or unusable due to incorrect or missing documentation. Step-level time allocations were often vague or inconsistent, which created significant difficulties in analyzing process behavior. This lack of accurate data reflects not only system limitations but again, a broader issue of awareness and accountability. While improving hour logging is critical for future performance monitoring, it is difficult to enforce without organizational commitment and a deeper recognition of repair process importance, a recurring theme throughout this thesis.

The third intervention, awareness training and structured communication, is perhaps the most important in terms of long-term cultural change. A lack of shared understanding about the role of repairs in overall performance is cited by both the repair coordinator and general planning coordinator as a root cause of delays and disengagement. However, these interventions target structural and behavioral issues that are difficult to address within the scope of this operational thesis. Moreover, their success is difficult to quantify, especially in the short term.

In contrast, fixed-cost pricing offers a solution that is directly tied to the core administrative bottleneck observed in both stakeholder interviews and quantitative data analysis: the delay caused by iterative quoting and customer approvals. This tool is scalable, repeatable, and measurable, and its impact can be tracked directly through changes in quoting speed, coordination time, and ROLT compliance. Furthermore, its feasibility has already been partially validated through the successful application of a fixed price to the item: *ALPHA V1*. As **Section 5.3.1** demonstrates, this intervention led to a marked reduction in process delays for that item.

In summary, while fixed-cost pricing provides a measurable and actionable first step, the long-term sustainability of ROLT compliance depends on the combined implementation of all four tools. Subsequent chapters address the broader roadmap required to embed these solutions into daily operations.

5.3.1. Performance Impact of Fixed Pricing on ALPHA V1

Figure 5.1 illustrates the performance impact of introducing fixed pricing for ALPHA V1. The y-axis shows the number of repair orders, with corresponding counts presented directly on each bar to improve interpretability. The comparison reflects repair order performance before and after the implementation of a fixed cost in early 2024.

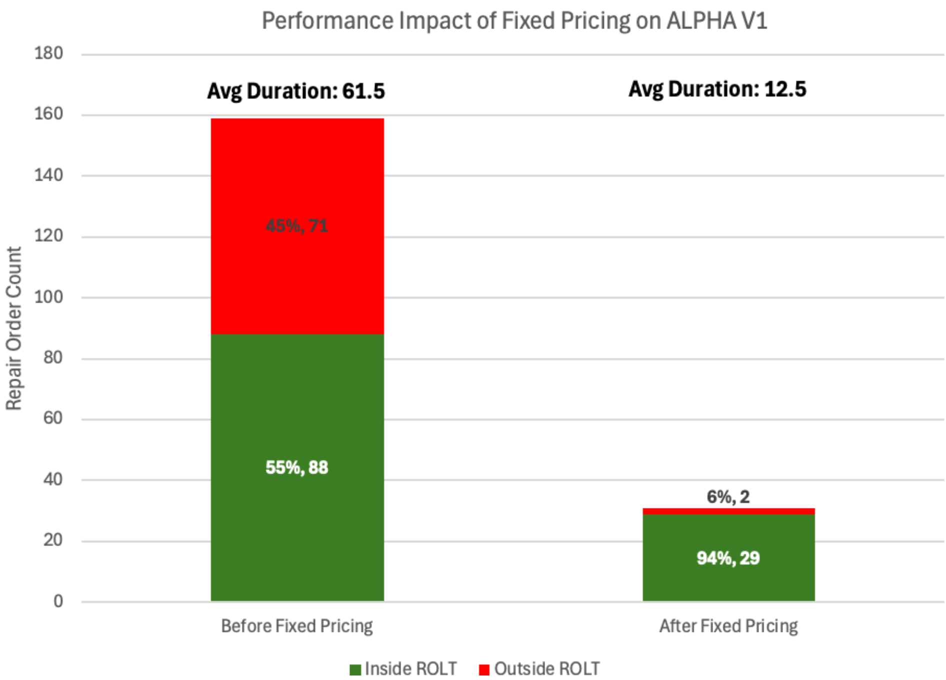

Figure 5.1: Before vs After Fixed Pricing on ALPHA V1

Prior to implementing fixed pricing, only 55% of ALPHA V1 repair orders were completed within the 51-day Repair Order Lead Time (ROLT) target. The average duration at that time was 61.5 days. As shown in Figure 5.1, this significantly improved post-implementation: 94% of repair orders are delivered on time, and the average duration drops to 12.5 days. Only two repair orders are outside ROLT after the change.

This intervention was a result of repeated delays that affected both NTS Hengelo and Company X. In response, both parties agreed in early 2024 to fix the price of ALPHA V1 repairs at **€2,155,** calculated based on historical repair costs. This eliminated the need for individual quoting and approval cycles, streamlining the administrative process and enabling quicker scheduling.

Unfortunately, the impact of fixed pricing on the step-level repair process cannot be further analyzed. After the price was standardized, stakeholders involved in the repair process do not clock in repair hours, likely due to the perceived irrelevance of detailed logging since the price is fixed. As a result, it became impossible to assess internal process behavior or efficiency gains beyond surface-level lead time analysis.

Hence, it is not possible to pinpoint which of the seven standardized repair steps has been directly improved. However, qualitative interviews with the repair coordinator suggest that the most significant reductions occurred between steps 3 and 6: Cleanroom Analysis (Step 3), Logistics and Planning (Step 4), Sales Communication with Customer (Step 5), and Cleanroom Execution (Step 6). This aligns with the findings from Chapter 4, which identified Steps 3, 4, and 6 as the most wasteful, together accounting for 87% of all unproductive time in the repair process.

This limitation highlights a recurring challenge identified in this thesis: the lack of accurate or complete ERP data, either due to incomplete documentation or a lack of perceived importance in maintaining it. While fixed pricing offers measurable performance benefits, the absence of detailed process data introduces risks. If repair complexity changes over time, the fixed cost may eventually become unrepresentative of real effort, potentially leading to cost overruns or undercompensation.

The implementation of fixed pricing for ALPHA V1 reflects a practical application of both Lean Thinking and Business Process Standardization. From a Lean perspective, the removal of the iterative quoting and approval steps between internal departments and Company X eliminates multiple forms of waste, most notably waiting and overprocessing. This directly aligns with the Lean principle of Continuous Flow, which seeks to ensure that administrative steps progress without interruption or delay. The repair process transitions into a smoother, uninterrupted flow by predefining the pricing structure. Thus, reducing both administrative workload and lead time. Simultaneously, the intervention also represents a form of process standardization, as it embeds a clear, repeatable cost framework for recurring repair items. This reduces ambiguity in pricing decisions, minimizes variation in coordination tasks, and supports more predictable planning. While fixed pricing alone does not address all the systemic issues in repair execution, it operationalizes core principles of these improvement frameworks. Thus, it serves as a measurable and scalable step toward reducing administrative inefficiencies and improving ROLT compliance.

In **Section 5.4**, the historical invoice data for all six targeted items are analyzed in detail to assess the feasibility of applying similar fixed pricing strategies. ALPHA V1 is included in that analysis as a benchmark case.

5.4. Fixed-Pricing Implementation

5.4.1. Purpose and Methodology

This section evaluates the feasibility of applying fixed-cost pricing to six recurring repair items, using a structured analytical approach aligned with the principles of Lean Thinking and Business Process Standardization.

The analysis draws on invoice data for all relevant repair orders completed between 2023 and March 2025. For each repair, the final invoice value sent to Company X is available, along with the corresponding material cost recorded in the ERP system. However, repair hours are not reliably clocked in the ERP system. Furthermore, the repair coordinator internally estimates the hours per repair so step-level information regarding the time allocation is not made available for this study. As a result, the analysis relies on reverse engineering to derive an estimate of the total labor hours per repair.

The derivation of labor hours is based on a structured methodology. For repair orders that involve only labor, the invoice value is divided by the agreed hourly rate of €98, as established between NTS Hengelo and Company X. In cases where both labor and materials are involved, the material cost is first adjusted by applying a 30% standard margin (i.e., multiplied by 1.3). This adjusted material value is then subtracted from the total invoice amount, and the remainder is divided by €98 to estimate the labor component, as shown in equation 5.1 below:

$$Estimated\ Labor\ Hours = \frac{(Final\ Invoive\ Value - (1.3\ \times\ Material\ Cost))}{98}$$

Equation 5.1: Estimated Labor Hours Calculation

Subsequently, repair orders are categorized based on common attributes, including the presence or absence of materials, the number of distinct materials used, and the total material value, where €500 serves as a critical threshold for classification. Each resulting group is analyzed to determine its average, minimum, maximum, and median invoice values, as well as the corresponding labor hours. Additionally, the coefficient of variation is calculated to evaluate pricing stability, and the frequency of each group is assessed to determine the feasibility of implementing a standardized pricing structure.

This process enables the identification of cost patterns that are both repeatable and stable, which are necessary conditions for proposing fixed pricing. For groups with low variability and sufficient historical frequency, fixed pricing becomes a viable option. For low-frequency but clearly patterned repairs, the average values may serve as templates for future quotation consistency.

It is important to note that this fixed-cost pricing analysis is based purely on financial patterns derived from invoice value, material quantity and cost, and estimated labor hours. The technical complexity of the repairs is not assessed in this framework. As a result, two repairs with similar financial profiles may differ significantly in terms of technical procedures, tooling, or complexity. Therefore, while this methodology is suitable for identifying pricing consistency, it does not capture the full technical diversity that may exist within or across repair items.

However, any variation in technical difficulty is expected to be indirectly reflected through differences in total labor hours and material usage, both of which impact the invoice value. These differences are captured quantitatively by the coefficient of variation, which serves as an indicator of pricing variability. In other words, repairs that are technically more complex and therefore require more time and resources will result in higher invoice values, thereby increasing variability. This ensures that such complexity-driven differences are at least partially accounted for in the financial assessment.

As a benchmark, this methodology is first applied to *ALPHA V1*, the only item that currently operates under a fixed pricing agreement. An analysis of 47 ALPHA V1 repair orders from 2023 in Table 5.1, prior to the implementation of fixed pricing, shows that the average total invoice value is approximately **€2,098 and a median of €2,155**, which closely aligns with the **€2,155 fixed price** introduced in early 2024. The coefficient variation (standard deviation/mean) shows a 20.9% in price stability. These repair orders fall into a single group referred to as *Category A – Labour only*: labor-only repairs with no material use. This uniformity reinforces the suitability of fixed pricing in cases with low variation. Moreover, it highlights the importance of grouping repair orders by bill of materials (BoM) content rather than by item code alone, as significant differences in complexity can exist within the same item.

ALPHA V1		
Category A - Labour only (47 ROs)		
	Euros	Hours
MIN	1505	15,36
MAX	3839	39,17
AVERAGE	2099	21,42
MEDIAN	2155	21,99
STD DEV	439	4,48
Coefficient of Variation	20,90%	

Table 5.1: Invoice and Labor Hour Statistics for ALPHA V1 Repair Orders (Pre-Fixed

In the following section, this grouping methodology is extended to the remaining six repair items to assess the viability of applying a similar fixed-pricing approach.

5.4.2. Analysis of ALPHA V2

Figure 5.2 presents the invoice price distribution for all 34 repair orders of ALPHA V2 completed between 2024 and 2025. This item, similar to ALPHA V1, has all its repair orders fall under *Category A – Labour only.* This category involves labor-only repairs with no material inputs, making it ideal for direct pricing evaluation without requiring further segmentation based on the BoM.

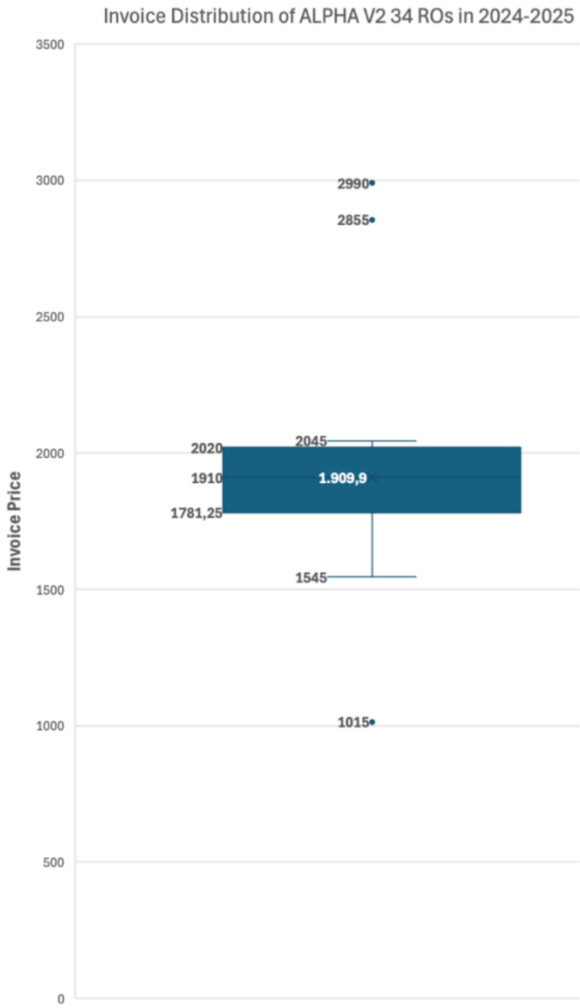

Figure 5.2: Invoice Distribution of ALPHA V2's 34 Repair Orders in 2024-2025

The visual analysis shows a **mean invoice value of €1,909.9** and a **median value of €1,910**, indicating a high degree of consistency. The calculated **coefficient of variation is 17.2%**, which is notably lower than the variation observed for ALPHA V1 (which stood at 20.9% prior to its price being fixed). This further supports the pricing stability of ALPHA V2 repairs.

Given the uniform nature of these repair orders and the relatively high number of historical repair orders, this item meets the criteria for fixed pricing as defined in **Section 5.4.1**: consistency, repeatability, and low pricing variability. In alignment with the logic applied to ALPHA V1, a proposed fixed price of **€1,910** is considered appropriate for future ALPHA V2 repairs. As with ALPHA V1, this fixed pricing approach eliminates the need for quotation-based approval cycles, which can otherwise delay steps 3 to 6, which account for 87% of the unproductive time.

5.4.3. Analysis of CHARLIE

Item CHARLIE has a total of 17 repair orders between 2023 and 2025. Unlike ALPHA V1 and ALPHA V2, where all historical repairs fell within a single labor-only category, the repair orders for this item show greater variability in complexity, primarily due to differences in material usage. As a result, the repair orders are grouped into three distinct categories based on identical BoMs.

CHARLIE						
	Category A – Labour Only (13 ROs)		**Category B – 1x High-Cost Material (2 ROs)**		**Category D - 3x Low-Cost Material (2 ROs)**	
	Euros	**Hours**	**Euros**	**Hours**	Euros	Hours
MIN	1,31	13.37	7,715	24.71	6715	66,43
MAX	2,815	28.72	7,715	24.71	6715	66,43
AVERAGE	2,205	22.50	7,715	24.71	6715	66,43
MEDIAN	2,18	22.24	7,715	24.71	6715	66,43
STD DEV	403	4.12	0	0	0	0
Coefficient of Variation	18.30		0		0	

Table 5.2: Invoice and Labor Hour Statistics for CHARLIE Repair Orders

Category A – Labor Only (13 ROs)
Similar to ALPHA V1 and ALPHA V2, the largest group consists of labor-only repair orders, requiring no materials. As shown in Table 5.2, this group has an **average invoice value of €2,205** and a **median of €2,180**, with a **coefficient of variation of 18.3%**, indicating a moderate but acceptable range of variation. The consistency in invoice values and the relatively high frequency of 13 ROs make this group a strong candidate for fixed-cost pricing. A proposed fixed price of **€2,200** is recommended for any future repairs that match this configuration.

Category B – 1x High-Cost Material (2 ROs)
This category includes two repair orders with identical BoMs, each involving one material with a cost above €500. As shown in Table 5.2, both were quoted at **€7,715**, resulting in **no observed variation**. Although the data supports a potential fixed price for this configuration, the current sample size is too small to implement pricing with confidence. However, this price point may serve as a reference template should additional repair orders of this type be observed.

Category D – 3x Low-Cost Materials (2 ROs)
Similarly, two repair orders share a BoM involving three distinct materials, each individually valued below €500. Both received identical quotes of **€6,715**, again producing a coefficient of variation of **0%**. As with Category B, the low frequency limits immediate implementation, but this segment should be monitored for repeat patterns. If the frequency increases, a fixed price of €6,715 may be adopted accordingly.

This case highlights the importance of using BoM-driven grouping to evaluate fixed pricing feasibility. While only Category A currently meets the threshold for immediate implementation, Categories B and D provide early signals for future standardization. As more repair orders are processed, these configurations should be revisited to assess if patterns become stable enough for formal price setting.

5.4.4. Analysis of BRAVO V3

Item BRAVO V3 has a total of 9 repair orders recorded between 2023 and 2025. While this item has a relatively low historical frequency, it has been highlighted by the repair coordinator as one expected to increase in frequency in the near future. This makes it a strong candidate for early fixed-pricing assessment, particularly to streamline administrative handling as its volume grows. The item's repair orders are divided into two distinct categories based on their material profiles.

BRAVO V3				
	Category D – 3x High-Cost Materials (7 ROs)		**Category E – More than 3 Materials (2 ROs)**	
	Euros	**Hours**	**Euros**	**Hours**
MIN	23,71	42.96	32,235	56.99
MAX	24,105	46.99	32,235	56.99
AVERAGE	23,878	44.67	32,235	56.99
MEDIAN	23,905	44.95	32,235	56.99
STD DEV	163	1.67	0	0
Coefficient of Variation	0.68%		0%	

Table 5.3: Invoice and Labor Hour Statistics for BRAVO V3 Repair Orders

Category D – 3x High-Cost Materials (7 ROs)
As shown in Table 5.3, this category consists of 7 repair orders that each involve three high-cost materials. The pricing across these repairs is notably consistent, with an **average invoice value of €23,878** and a **median of €23,905**. The **coefficient of variation is only 0.68%**, suggesting minimal variability. This group exhibits a strong level of pricing stability with sufficient frequency to justify the implementation of a fixed cost. A proposed rounded fixed price of **€23,900** is therefore considered appropriate for future repairs falling under this configuration.

Category E – More Than 3 Materials (2 ROs)
This category includes 2 extensive repair orders involving 21 materials each, with both repairs sharing **identical bills of materials** and resulting in identical invoice values of **€32,235**. The absence of variation, as shown in Table 5.3, confirms the internal consistency of this group.

However, due to the limited frequency, it is not yet advisable to implement fixed pricing. This configuration should be monitored over time, especially given the expected rise in repair volume for this item. If future repairs match this same BoM, a fixed price of **€32,235** may be formalized. That said, it is important to acknowledge that higher prices also carry higher risk. If a repair unexpectedly turns out to be more complex and time-consuming than anticipated, NTS Hengelo absorbs the financial burden under the fixed pricing model. In order to mitigate this risk, a larger historical dataset and/or better scope definitions such as more detailed technical assessments, may be necessary to ensure pricing robustness and avoid misestimations.

5.4.5. Analysis of BRAVO V2

Item BRAVO V2 accounts for a total of 16 repair orders completed between 2023 and 2025. Compared to other items, this component exhibits a high degree of variability in terms of materials used, leading to the creation of six distinct categories based on consistent bill of materials (BoM) patterns. While only two categories currently meet the criteria for fixed pricing, the remaining groups may be revisited as additional repair orders become available in the future.

BRAVO V2				
	Category A – Labour Only (9 ROs)		Category B – 1x High-Cost ROs)	Material (3
	Euros	Hours	Euros	Hours
MIN	1,765	18.01	8,13	25.59
MAX	4,175	42.60	11,414	59.10
AVERAGE	2,522	25.74	9,225	36.76
MEDIAN	2,39	24.39	8,13	25.59
STD DEV	616	6.29	1,548	15.80
Coefficient of Variation	24.44%		16.78%	

Table 5.4: Invoice and Labor Hour Statistics for BRAVO V2 Repair Orders

Category A – Labor-Only Repairs (9 ROs)
As shown in Table 5.4, this group includes 9 repairs without any material usage. The **average invoice value is €2,522**, and the **median is €2,390**, resulting in a **coefficient of variation of 24.4%**. While this variation is slightly higher than that observed in similar labor-only categories (e.g., ALPHA V1 and ALPHA V2), it remains within an acceptable range given the high frequency of occurrence. For this reason, a **standardized price range between €2,500 and €2,550** is considered appropriate for labor-only repairs that match this configuration.

Category B – 1x High-Cost Material (3 ROs)
This category contains 3 repairs that each involve the **same high-cost material** in a quantity of one. As detailed in Table 5.4, the average invoice value is **€9,225**, and the coefficient of variation is **16.78%**. This moderate variation, combined with the small but sufficient sample size, makes this category a **viable candidate** for fixed pricing. A tentative fixed price of **€9,200** may be considered, pending further validation through additional repairs.

Category C – 2x High-Cost Material (1 RO)
This category consists of a single repair involving **two units of the same high-cost material** used in Category B. The invoice value is **€14,395**. While the consistency in material type provides a logical extension from Category B, the **low frequency (n = 1)** precludes immediate implementation of fixed pricing. This configuration should be monitored for recurrence.

Category D – 3x High-Cost Material (1 RO)
Category D includes a single repair with **three units of the same material** used in Categories B and C, quoted at **€20,590**. While this shows logical cost progression based on material quantity, the group is currently **limited to one case** and should similarly be flagged for future observation.

Category D (Second Instance) – 3x High-Cost Material (1 RO)
This is a **second instance** of a three-material repair, but with **a different material type** than that of Categories B–D. The invoice for this repair is **€9,420**. Given the unique BoM and single occurrence, no pricing recommendation can yet be made.

Category E – More Than 3 Materials (1 RO)
This final category involves an **extensive repair with 23 distinct materials**, resulting in an invoice value of **€28,280**. Although highly consistent in itself, the **lack of recurrence** limits immediate pricing action. However, if this configuration reappears, it may serve as the basis for a fixed quote due to its standardized cost.

5.4.6. Analysis of BRAVO V1 & *DELTA*

Two additional items, BRAVO V1 and DELTA, were initially considered in this analysis but are ultimately excluded from deeper evaluation due to insufficient and inconsistent data.

BRAVO V1
A total of **four repair orders** are identified for BRAVO V1 between 2023 and 2025. Each of these had a **unique bill of materials**, and invoice values varied accordingly. However, a major limiting factor in this case was the **incomplete and inconsistent documentation** of material costs within the ERP system. In several instances, materials were either missing, misclassified, or lacked associated pricing information.

This challenge reflects a broader pattern of substandard documentation discussed in earlier sections (see Section 4.2), reinforcing the difficulty in drawing meaningful conclusions from ERP data when process inputs are not consistently tracked.

Even if documentation were complete, the lack of repeated BoM configurations would have prevented fixed pricing recommendations. At best, each case could have served as an initial template for future categorization if similar repair orders emerge.

DELTA
For DELTA, **only a single repair order** was recorded in the available dataset. Given the absence of comparable cases, no meaningful analysis can be performed, and **no pricing pattern** can be established at this stage.

5.4.7. Analysis Summary

As shown in Table 5.5, the fixed pricing analysis has yielded actionable outcomes for the majority of item segments, particularly those with high repair frequency, low price variability, and consistent Bill of Materials (BoM). Specifically, four categories, each associated with more than three repair orders and identical BoMs, demonstrate strong feasibility for immediate fixed-price implementation. These categories collectively account for 63 of the 77 repair orders analyzed, underscoring their operational relevance and scalability.

Item	Category	Average Price €	# of ROs	Avg Hours	Price of Materials €	CV	Bill of Materials (BoM)
ALPHA V2	**A** –Labour-Only	1910	34	19,5	-	17,20%	No Materials Involved
BRAVO V3	**D** – 3x High-Cost Materials	23900	7	45	15000	0,68%	3x ZULU
BRAVO V3	**E** – More than 3 Materials	32235	3	57	20500	0	10x Materials
BRAVO V2	**A** –Labour-Only	2500	9	26	-	24,44%	No Materials Involved
BRAVO V2	**B** – 1x High-Cost Material	9200	3	37	4325	16,78%	1x ZULU
BRAVO V2	**C** – 2x High-Cost Materials	14400	1	32	8650	0	2x ZULU
BRAVO V2	**D** – 3x High-Cost Materials	20600	1	38	12975	0	3x ZULU
BRAVO V2	**D** – 3x High-Cost Materials (Second Instance)	9420	1	23,5	5485	0	3x YANKEE
BRAVO V2	**E** – More than 3 Materials	28280	1	26	19815	0	23x Materials
CHARLIE	**A** –Labour-Only	2200	13	22,5	-	18,30%	No Materials Involved
CHARLIE	**D** – 3x Low-Cost Materials	6715	2	66,4	157	0	1x VICTOR 2x TANGO
CHARLIE	**B** – 1x High-Cost Material	7715	2	24,71	4075	0	1x SIERRA

Table 5.5: Summary of Fixed Pricing Feasibility for Recurring Repair Items

Additionally, segments with exactly three repair orders, while fewer in number, present identical invoices and BoM configurations, making them reasonable candidates for near-term fixed pricing. Their pricing regularity suggests readiness for implementation if stakeholder alignment is achieved. In contrast, categories with only one or two matching repair orders are not yet suitable for fixed pricing but should be monitored as templates. As more data becomes available, these templates can help validate consistency and justify future price standardization.

However, two items remain unsuitable for fixed pricing at this stage due to either low repair frequency or inconsistent documentation. Their inclusion highlights the need for a structured, repeatable methodology that can support fixed-price decisions across time and product types. To address this need, the following section introduces a step-by-step categorization framework presented as a flowchart. This framework ensures consistency in how historical and future repair orders are segmented based on BoM and price variation.

5.5. Categorization Flowchart for Fixed Pricing

To ensure consistency and scalability in setting fixed prices for repair orders, a structured decision-making framework is introduced in Figure 5.4. This flowchart provides a step-by-step logic for categorizing historical and future repair orders based on their **BoM** and price consistency.

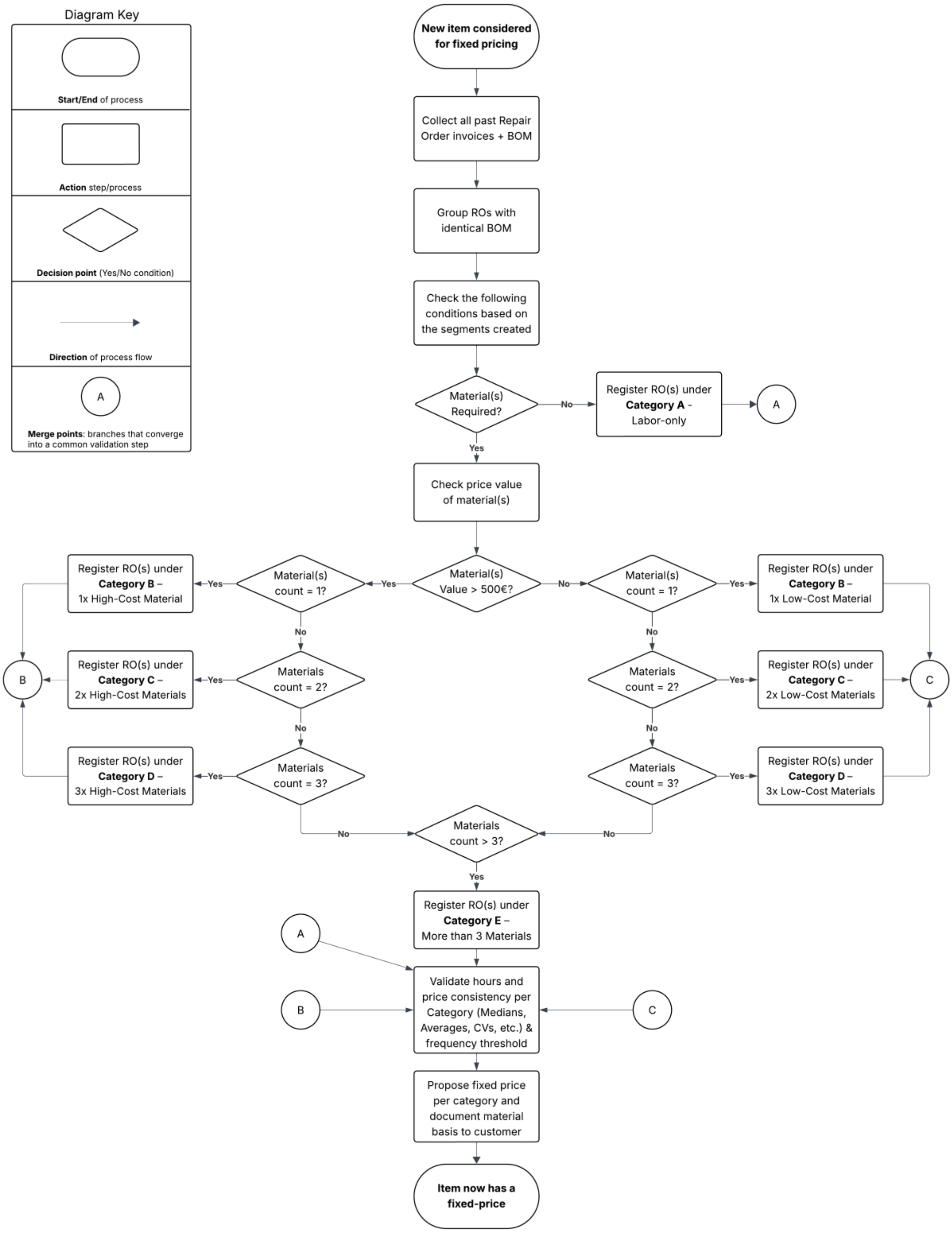

Figure 5.3: Categorization Flowchart for Fixed Pricing

A key principle in this framework is the grouping of repair orders with identical BoMs. As demonstrated in the analysis of **Section 5.4**, grouping by identical material composition enables meaningful segmentation of repair orders into repeatable patterns. This is particularly critical in environments such as NTS Hengelo's, where repair complexity can vary widely. Without BoM-based segmentation, repair orders may be inappropriately grouped, masking true variability and leading to inaccurate pricing assumptions.

The flowchart begins by collecting all past invoices and BoMs for a given item. Based on whether materials are involved, the item is assigned to one of several predefined categories:

- **Category A** for labor-only repairs,
- **Categories B–D** based on the number and cost of materials, and
- **Category E** for extensive repairs involving more than three materials.

Each category is then validated for consistency in pricing (using metrics such as averages, medians, and coefficient of variation) and frequency, to determine its eligibility for fixed pricing. Based on the cases analyzed, a minimum of five repair orders may position an item as a contender for fixed pricing consideration. If the number of repair orders is at least 10 to 15 and is expected to increase over time, then fixed pricing becomes fully applicable.

Additionally, the coefficient of variation (CV) is a critical indicator of pricing stability. As established in the benchmark case of ALPHA V1, which had a CV of approximately 21%, a maximum threshold of 20–25% is proposed for fixed pricing implementation. However, for high-value item categories, where pricing risks are more sensitive, a more conservative threshold of 10-15% CV may be advisable to ensure pricing reliability and protect against underestimating labor or possible technical complexities.

While this framework has already been applied to the six items analyzed in Section 5.4, its value extends beyond these cases. It provides NTS Hengelo with a repeatable structure to evaluate any future repair item, such as DELTA, particularly those expected to rise in volume. Even when past data is limited, this approach offers a template to classify and track incoming repairs and assess their eligibility for standardization over time.

Moreover, it is important to recognize that the final decision to adopt fixed pricing is not solely internal to NTS Hengelo. As pricing is contractually agreed upon with Company X, presenting a transparent, data-driven methodology strengthens NTS Hengelo's case and facilitates constructive negotiation. By justifying proposed fixed prices with historical performance, material consistency, and volume trends, the company can provide a clearer rationale for standardization, enhancing cross-organizational alignment.

In summary, this flowchart institutionalizes a Lean-compatible process for classifying repairs and standardizing pricing. It not only reduces administrative overhead and quotation delays but also fosters a more proactive approach to repair process management.

Chapter 6 builds now on these findings by exploring what additional process and system changes are required for NTS Hengelo to consistently achieve the 90% ROLT compliance target. It will also analyze the expected impact of implementing fixed pricing, both in terms of operational lead time and broader organizational performance.

6. Impact Analysis and Strategic Recommendations

This chapter addresses the final set of research sub-questions by analyzing the observed and expected impact of resolving administrative bottlenecks in NTS Hengelo's repair process. **Section 6.1** evaluates how the streamlined process flow for fixed-pricing items improves operational performance. More specifically, Repair Order Lead Time (ROLT) compliance, thus answering core Sub-question 5: *What impact is expected from resolving the identified bottlenecks on NTS Hengelo's Repair Order Lead Time (ROLT) performance?*

Building on this impact analysis, **Section 6.2** explores further system and process changes required to sustain these gains, answering supporting Sub-question 5.1: *What additional process or system changes are necessary to help NTS Hengelo consistently achieve the 90% ROLT compliance target?* These include recommendations to improve ERP logging, stakeholder awareness, and repair execution visibility.

Finally, **Section 6.3** delivers a tailored set of short- and long-term recommendations grounded in the findings from this study, directly addressing core Sub-question 6: "*What tailored, evidence-based recommendations can be made to NTS Hengelo based on the findings from this research?"*

Together, these three sections synthesize the research's operational findings into actionable strategies aimed at improving process efficiency, stakeholder alignment, and ROLT performance sustainability.

6.1. Improved Repair Process Flow for Fixed-Pricing Items

This section builds directly on the baseline repair process outlined in **Section 2.3**, which detailed the complexity and fragmentation of the current administrative workflow at NTS Hengelo. In this section, the updated process flow for items operating under a fixed-pricing model is presented, highlighting the specific changes that improve efficiency and standardization. Figure 6.1 below introduces the revised BPMN diagram showing the repair order flow for items that now follow a fixed-pricing structure.

The process introduces one new standardized activity, **"Categorize repair order based on BoM"**, which is informed by the categorization flowchart developed in **Section 5.5**. This categorization step is not an administrative bottleneck but is performed in parallel while the item is physically present in the cleanroom and being executed. Since prices for each BoM category are predetermined, the step merely identifies the correct pricing segment, making quoting and approval steps obsolete.

This design change leads to the elimination or streamlining of Steps 3 to 6: Step 3: Cleanroom analysis, Step 4: Logistics and planning, Step 5: Sales communication to customer, and Step 6: Cleanroom execution.

As identified in **Chapter 4**, these steps together account for **87% of all unproductive time** in recurring items. Their removal or simplification is a core contributor to the performance improvement observed in the item ALPHA V1, which fully follows the fixed-pricing model.

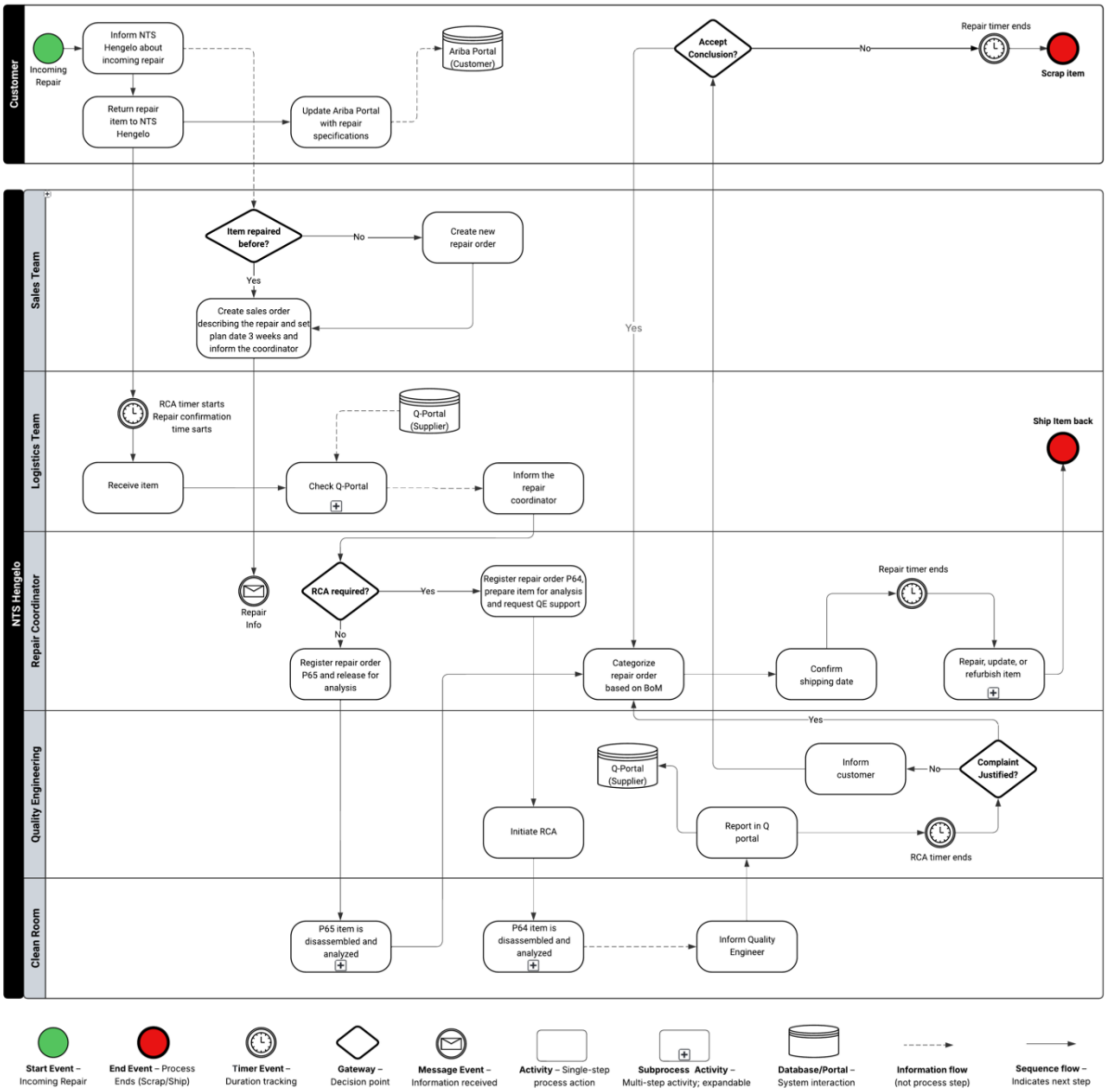

Figure 6.1: Updated BPMN Diagram for Fixed-Pricing Repair Orders

Figure 6.2 illustrates the ROLT compliance of recurring items prior to fixed pricing interventions. ALPHA V1, shown on the far right, had a compliance rate of just **55.35%**, indicating that nearly half of its repair orders exceeded the ROLT target of 51 days. After implementing fixed pricing for ALPHA V1, along with associated process simplifications outlined in the updated BPMN, its performance improved markedly. The **average duration decreased from 61.5 days to 12.5 days**, representing an **80% reduction**, and **ROLT compliance rose to 94%**, a **39-percentage-point improvement**. While Figure 6.2 only reflects the pre-intervention status, ALPHA V1 serves as a clear example of the tangible impact fixed pricing can have when paired with streamlined administrative procedures. A detailed breakdown of time saved per step is unavailable, as repair hours were no longer clocked after the pricing change. However, the significant improvement in lead time and compliance reinforces the conclusion that administrative inefficiencies were a primary bottleneck.

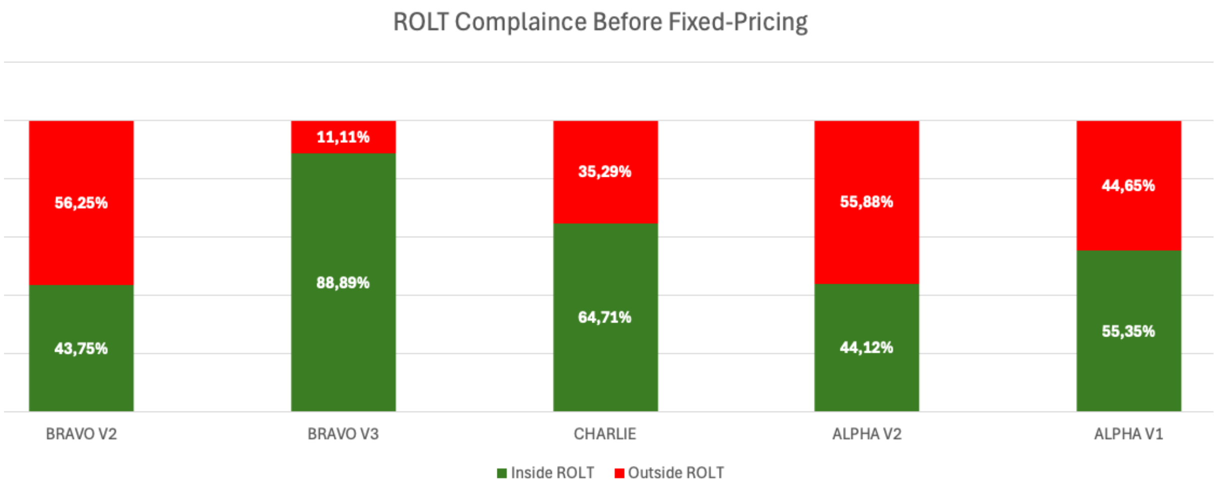

Figure 6.2: ROLT Compliance for Recurring Items Before Fixed Pricing

Importantly, this improvement is not just theoretical. Interviews with NTS Hengelo stakeholders confirm the operational relief brought by fixed pricing. The repair coordinator noted that most delays happen in these administrative steps. These views align directly with the theoretical foundations of Lean Thinking and Business Process Standardization. Lean emphasizes continuous flow and waste elimination, particularly waiting, overprocessing, and administrative inefficiency. Standardization reduces interpretation and handoff errors, enabling consistent, scalable execution.

However, this streamlined BPMN assumes a key condition: that the proposed category-based fixed prices are already approved by Company X. Additionally, a fundamental barrier lies in the inconsistent or absent ERP documentation across the repair process. Many repair orders are either partially logged or missing critical timestamps, making it difficult to measure performance improvements or ensure traceability. Addressing this challenge requires greater awareness and commitment from all process stakeholders, particularly cleanroom technicians and administrative staff, to consistently clock repair durations and document item progression accurately. These systemic dependencies and risks are examined in the following section.

6.2. Additional System/Process Changes

6.2.1. Improve ERP Logging Compliance

While the introduction of fixed pricing has removed the need for quoting hours and materials, it does not eliminate the necessity of accurately tracking repair progress. In fact, consistent logging of repair steps and durations becomes even more important in a standardized system. Without reliable ERP input, NTS Hengelo cannot monitor process performance, identify deviations, or validate the continued suitability of fixed prices.

Currently, ERP logging across the repair process is inconsistent. As shown in Chapter 4, 18.2% of repair orders in 2024 had incomplete or missing data. This issue was further compounded after fixed pricing was introduced for item ALPHA V1: stakeholders no longer clocked in hours post-standardization, under the assumption that fixed pricing removed the need for tracking. This behavior introduces a critical visibility gap in a process that otherwise aims to be repeatable, measurable, and efficient.

The importance of complete and consistent ERP usage is well-documented in the literature. According to Spathis & Constantinides (2003), system success is directly linked to the quality of input data and continued user engagement. Without reliable information logged by users, the effectiveness of the ERP system declines, and management loses the ability to make data-driven decisions. Moreover, Spathis & Constantinides (2003) emphasize that standardized processes only deliver performance gains when documentation is followed rigorously across all user levels.

To improve ERP logging compliance, several measures are recommended:

- **Clarify expectations through retraining:** Stakeholders must be reminded that tracking remains essential for performance analysis, planning accuracy, and long-term sustainability of fixed pricing.
- **Enable system-based nudges:** Underutilized ERP capabilities, such as automated reminders or mandatory time entry checkpoints, can be activated to prompt users to log progress.
- **Align messaging from supervisors and coordinators:** Stakeholders interviewed during this study confirmed that inconsistent logging is often seen as "non-essential," especially for repairs deemed low priority. A top-down emphasis on process discipline may be necessary to embed tracking behavior.

Ultimately, standardizing pricing without maintaining data discipline risks undermining the very efficiencies that the new model seeks to deliver. Repair stakeholders must remain actively engaged in ensuring data traceability, not as a bureaucratic formality but as a critical part of process transparency and improvement.

6.2.2. Communication & Awareness Building

While technical interventions such as fixed pricing and ERP system enhancements provide structural support for reducing lead times, they must be complemented by improved communication practices and stakeholder awareness to be effective in the long term. During the course of this research, several stakeholder interviews revealed that a core issue underlying many of the administrative inefficiencies was not the absence of tools, but a lack of shared understanding about the importance of repairs and their operational priority.

In particular, repairs are often perceived as secondary to new builds, leading to delays in execution even when administrative barriers have been removed. This perception affects prioritization in the cleanroom, with planners frequently shifting resources away from repair orders. Moreover, stakeholders across departments such as sales, logistics, cleanroom, and planning, often operate in silos without clear communication protocols or shared responsibility over ROLT compliance.

To address this, several actions are recommended:

- **Awareness-building campaigns:** Short internal workshops, onboarding briefings, or targeted communications should be introduced to educate relevant staff about the importance of repair lead times. This includes explaining the external KPI (90% ROLT compliance), the strategic value of customer satisfaction, and the internal benefits of improved repair performance. Showcasing the ALPHA V1 case, where average duration decreased by 80% and ROLT compliance rose to 94%, can help make the message concrete.
- **Defined communication routines:** Communication between departments should follow a consistent structure. For example, once a repair order is categorized and

ready, a standardized message or ERP notification can be sent to cleanroom staff. Clear ownership should be established for each handoff step to prevent idle time.
- **Leadership reinforcement:** Team leaders and coordinators should regularly reiterate the financial and sustaianble value of repairs during planning meetings and daily huddles. This top-down reinforcement helps shift the narrative from “repairs as disruption” to “repairs as critical service,” especially when accompanied by visible KPIs or positive results.

Building awareness is not an isolated intervention, it must be embedded into the culture of the repair process through consistent messaging, visual reminders, and role clarity. Without it, even well-designed processes and pricing models risk being undermined by passive neglect or organizational inertia.

While the interventions discussed above focus on raising awareness and improving communication within the existing process, they may not be sufficient to address deeper structural and cultural barriers. In this context, Business Process Reengineering (BPR) could serve as a valuable future direction. This implementation enables Hengelo to fundamentally rethink the coordination, ownership, and visibility of the repair process across departments. Although this thesis aims to resolve a specific operational bottleneck, a broader reengineering initiative may be necessary to embed repairs more firmly into organizational priorities and eliminate systemic fragmentation. This could serve as a foundation for future research.

6.2.3. Repair Scheduling & Prioritization

A recurring insight throughout this study is that cleanroom execution, although technically streamlined by the removal of administrative quoting steps, remains vulnerable to delays due to inconsistent scheduling discipline and limited operational visibility. While fixed pricing accelerates the transition to repair execution, this improvement can only be sustained if repair orders are properly prioritized and actively managed on the shop floor.

Currently, cleanroom workers often prioritize new builds over repairs, especially when planning enforcement is weak or when the visibility of repair orders is low. Interviews with stakeholders confirmed that even when a repair order is ready to execute, it may remain idle due to resource shifts, lack of urgency, or insufficient tracking cues within the cleanroom environment.

NTS Hengelo can benefit from implementing **visual assistance tools** that highlight repair status in real time to strengthen compliance with planning, improve scheduling discipline, and ensure that execution steps are clearly visible to cleanroom workers. This visibility reinforces task ownership and helps reduce idle time between handoffs. Several digital tools are suitable for this purpose:

- **Microsoft Power BI** offers dynamic dashboards that can connect to ERP data sources and present repair order status, ROLT compliance, and task progression in real time. This tool is well-suited for installation in cleanroom displays or planning rooms, providing cleanroom technicians and coordinators with clear visual indicators of pending and urgent repair orders. This tool provides detailed visualizations (Zadeh et al., 2020).
- **Odoo Dashboards** provide low-code options to create visual workflows, job cards, and colored status fields within the repair module itself (Ardianti et al., 2021). These dashboards can include real-time indicators such as “Waiting,” “In Progress,” or

“Delayed,” and help streamline internal coordination without requiring external software.

In addition to digital dashboards, NTS Hengelo can benefit from incorporating non-digital visual assistance tools to improve prioritization discipline in cleanroom operations. These tools offer simple, low-cost solutions that can be deployed with minimal setup and still provide meaningful support in environments where digital infrastructure is either unavailable or underutilized.

- **Color-coded tags:** affixed directly to the repair order boxes. These tags indicate the urgency of each repair based on the remaining days before breaching the ROLT KPI threshold. For instance, a green tag may represent 40–50 days remaining, orange for 30–40 days, and red for fewer than 30 days. Alternatively, a designated cleanroom table may be divided into colored zones using adhesive markers or tape, with each zone corresponding to one of these lead-time categories. By physically positioning repair items in the respective zones, cleanroom staff are provided with a clear and immediate visual cue of scheduling urgency.
- **Job traveler sheet**: a physical document accompanying each repair order box. This sheet is manually updated and signed by personnel at each process step, noting the time spent and responsible operator. While this method requires discipline in manual entry, it reinforces accountability and offers a basic, tangible form of process tracking in environments where system-based time logging may be inconsistent.

While these non-digital tools are advantageous due to their low cost and ease of implementation, their static nature and reliance on manual updates present limitations in maintaining real-time visibility and coordination. In contrast, digital tools such as Power BI and Odoo dashboards offer dynamic, ERP-integrated visualizations that support real-time repair tracking, ROLT compliance monitoring, and workflow progress updates. These tools, however, require more complex setup and potentially higher investments in infrastructure, training, and maintenance.

Both tool types serve distinct operational contexts. Digital dashboards are better suited for cleanroom displays or coordination rooms where ERP integration is feasible and desired. Non-digital tools, on the other hand, provide an immediate and scalable solution where real-time systems are not yet fully adopted. By integrating either or both approaches, NTS Hengelo can significantly improve cleanroom task visibility, reinforce planning compliance, and reduce idle time between handoffs. Future research may further explore the behavioral impact of such tools and assess the comparative effectiveness of digital versus physical visual formats for engaging cleanroom personnel and sustaining ROLT performance.

Ultimately, fixed pricing removes approval barriers, but visual prioritization tools may help execution in the cleanroom happen without delay, especially in high-mix, low-volume environments where manual oversight may be limited. Future research could further evaluate the behavioral impact of these tools and the most effective visual formats for engaging cleanroom personnel.

6.3. Final Recommendations

6.3.1. Short-Term Recommendations

To translate the findings of this research into a tangible impact, NTS Hengelo should prioritize a set of short-term actions that can be implemented within the next three months. This timeline is critical, as the fixed pricing approach, while validated through historical analysis, must also be formally agreed upon with Company X before it can be fully operationalized.

The following recommendations aim to maximize the impact of process standardization and administrative simplification in the near term:

- **Implement fixed pricing for high-frequency, consistent repair categories:** As outlined in **Section 5.4.7**, four item categories (comprising 63 of the 77 analyzed repair orders) have sufficient frequency, identical BoMs, and low price variation to justify immediate fixed pricing. These categories should be prioritized in the negotiation with Company X to finalize and lock in fixed rates for each segment. This step alone can reduce administrative lead time and increase ROLT compliance for the most recurring repairs.
- **Assign internal ownership for category tracking:** For item categories with two or three repair orders, particularly those that show identical BoMs and identical invoices, a fixed price may not yet be justifiable. However, these categories should be flagged as candidates for future standardization. The repair coordinator should be formally assigned responsibility for monitoring incoming ROs to detect BoM matches and flag repeating patterns that meet the fixed pricing criteria defined in **Section 5.5**. This ensures the framework remains active and scalable without waiting for another full study.
- **Initiate ERP compliance and training campaigns:** As detailed in Section 6.2.1, the lack of consistent ERP time logging impedes performance tracking and future analysis. Immediate efforts should focus on communicating the continued importance of ERP usage, even in fixed-price scenarios, and providing training to reinforce correct procedures. The goal should be to ensure that repair execution is both standardized and traceable, allowing NTS Hengelo to track improvements, evaluate repair durations, and maintain data quality.

Together, these short-term recommendations form the foundation for broader organizational change. They are not only feasible but essential to ensuring that the fixed pricing model delivers measurable improvements, both for NTS Hengelo and Company X, within a reasonable time frame.

6.3.2. Long-Term Recommendations

While short-term actions will enable immediate process improvements, a second phase of interventions should begin at the **start of 2026**, once sufficient repair data from 2025 is available for evaluation. This longer-term perspective is essential for capturing emerging repair patterns, identifying any new bottlenecks, and ensuring that NTS Hengelo continues progressing toward consistent ROLT compliance.

The following recommendations are designed to support sustainable process maturity and data-driven decision-making over time:

- **Integrate fixed pricing categorization into the onboarding of new items**
  For repair items with no historical records, such as DELTA, the categorization framework presented in **Section 5.5** can be used as a template for rapid evaluation as data accumulates. By segmenting incoming repair orders based on BoM consistency and frequency, NTS Hengelo can proactively determine whether an item may become a candidate for fixed pricing. This makes the pricing model scalable to future growth areas without requiring a full reanalysis.
- **Monitor growth trends and reapply bottleneck identification methods**
  Using the methodology introduced in **Chapters 3 and 4,** NTS Hengelo should regularly evaluate ROs for recurring delays or emerging process inefficiencies. This includes tracking item frequency, step-level durations, and compliance with the 51-day ROLT KPI. Bottlenecks are not static, they may shift as new items are introduced or production priorities evolve. Reapplying this methodology annually allows the organization to remain responsive and evidence-based in its continuous improvement.
- **Prioritize awareness-building campaigns before implementing visual dashboards**
  As discussed in **Section 6.2.2**, current process challenges are not only technical but cultural. Before deploying digital dashboards or visual aids, NTS Hengelo must first ensure that repair stakeholders fully understand the importance of repairs, their impact on company KPIs, and their role in standardized process execution. Once this awareness is actively reinforced, through internal communication, leadership messaging, and visible metrics, visual dashboards can be introduced to strengthen operational visibility. Potential platforms include: **Microsoft Power BI** and **Odoo Dashboards**.

In order to enhance the practicality of visual dashboard implementation, NTS Hengelo should initiate a pilot project by selecting a small set of critical repair KPIs. These KPIs should include ROLT compliance and pending order counts for initial visualization. This pilot can utilize Microsoft Power BI or Odoo Dashboards to create basic, real-time status indicators, displayed in a central cleanroom location. Feedback should be collected from cleanroom staff and planners during the pilot phase to refine the dashboard design before scaling up. This phased approach ensures early user involvement, minimizes resistance, and enables the dashboards to be tailored to operational needs, improving adoption and effectiveness.

These long-term recommendations aim to reinforce and expand the process improvements initiated in 2025. By institutionalizing repair evaluation, maintaining stakeholder alignment, and strategically introducing visual tools, NTS Hengelo can ensure that its repair operations remain efficient, traceable, and consistently aligned with the 90% ROLT compliance target.

7. Conclusion

This final chapter consolidates the findings of the research by revisiting the main research question and its supporting sub-questions, presenting the overall conclusion drawn from the analysis. It also reflects on the study's limitations and explores future opportunities for research and improvement. Finally, it outlines the contributions this thesis makes to both academic theory and practical applications within high-mix, low-volume repair environments.

7.1. Conclusions

Consistently meeting repair performance expectations is critical for NTS Hengelo, particularly given the performance agreements in place with its primary customer, Company X. One of the key targets is achieving at least 90% compliance with the Repair Order Lead Time (ROLT) KPI every month. However, by late 2024, NTS Hengelo was averaging just 80.3% compliance. To understand and address the reasons for this performance gap, this thesis investigated the operational challenges in the current repair process. The central research question guiding the study was therefore:

"How can NTS Hengelo consistently achieve and sustain 90% from an 80.3% on-time repair order completion by identifying and reducing recurring bottlenecks in the repair process?"

The research adopted the Managerial Problem-Solving Method (MPSM) as a structured framework to answer this question.The study was broken down into six core sub-questions, some with supporting sub-questions, with supporting sub-questions used to ensure depth and coherence. Each sub-question is revisited below:

Sub-question 1: What KPIs, set by Company X, are currently used to evaluate the repair process at NTS Hengelo?

As explored in **Chapter 2**, Company X evaluates supplier repair performance using two primary Key Performance Indicators (KPIs). The first is the **Supplier Repair Rate**, which measures the percentage of repairs required relative to delivered products. This metric was not the focus of this study, as NTS Hengelo consistently performs above the required threshold. The second, and more relevant KPI, is the **Repair Order Lead Time (ROLT)**, which measures the percentage of repair orders completed within 51 calendar days. This target is set at 90%, and it served as the central performance metric throughout this research. At the time of analysis, NTS Hengelo was achieving 80.3% compliance, underscoring the need to investigate and resolve underlying process inefficiencies.

Sub-question 2: *What does the current repair process flow at NTS Hengelo entail?*
Supporting sub-question 2.1: *How are different types of repairs categorized and handled within this workflow?*

Sections 2.2 and 2.3 outlined the current repair process at NTS Hengelo using a descriptive overview and a BPMN (Business Process Model and Notation) diagram. The process involves two distinct types of repair flows: **P64 repairs**, which require Root Cause Analysis (RCA), and **P65 repairs**, which do not. These flows differ in structure but both engage multiple departments, including the cleanroom technicians, logistics staff, the repair coordinator, and the sales team.

A key contextual insight was that **53% of repair orders processed in 2024 involved discontinued items**, which contributed to the phasing out of part-time cleanroom personnel. This reinforced the strategic importance of enhancing lead time performance for active items**,** not only to meet the existing KPI requirements but also to strengthen the case for increasing repair intake from Company X.

Sub-question 3: *What are the major bottlenecks in NTS Hengelo's repair process?*
Supporting sub-question 3.1: What structured methods can be used to identify process bottlenecks aimed at improving the repair process performance at NTS Hengelo?
Supporting sub-question 3.2: *Which of these bottleneck identification methods are suitable for application to NTS Hengelo's repair process?*

Chapter 3 provided a review of six bottleneck identification methods, grouped into two broad categories: traditional approaches and emerging data-driven methods. Based on conceptual fit, data availability, and relevance to NTS Hengelo's environment, two methods were selected for application in **Chapter 4**: Pareto Analysis and ERP/Excel based Process Mining. The combination of these tools proved effective in identifying both item-level and step-level bottlenecks. Six recurring items were ultimately selected for in-depth analysis based on delay frequency, expected recurrence, and stakeholder input. These items were then evaluated at a step-by-step level, revealing that three of the seven repair process steps, specifically, Steps 3 (Cleanroom Analysis), 4 (Logistics & Planning), and 6 (Cleanroom Execution), accounted for approximately 87% of the total unproductive time**.**

Sub-question 4: *What are the solutions to address the identified bottlenecks in NTS Hengelo's repair process?*
Supporting sub-question 4.1: *What structured methods can be utilized to resolve bottlenecks and improve the operational performance of NTS Hengelo?*
Supporting sub-question 4.2: *Which of these resolution methods are most applicable to the context of NTS Hengelo's repair process?*

Chapter 5 explored three theoretical approaches to process improvement: Lean Thinking, Business Process Standardization, and Business Process Reengineering (BPR)**.**

Building on these frameworks, the chapter translated theory into four actionable tools:

1. **Fixed-cost pricing categories**, aimed at eliminating administrative delays caused by repeated quotation approvals.
2. **Visual dashboards for cleanroom workers**, designed to enhance process visibility and task clarity.
3. **Communication and awareness initiatives**, to strengthen commitment and understanding of the repair process's importance.
4. **ERP hour logging compliance**, to ensure accurate process data and enable performance monitoring.

Following a structured evaluation, **fixed-cost pricing** was selected as the primary intervention due to its high scalability, quantifiable impact, and alignment with both Lean and Standardization principles. Its selection was also supported by evidence from ALPHA V1, which had already undergone a successful fixed-pricing implementation. A flowchart-based categorization framework was developed to guide the identification of repair orders suitable for fixed pricing based on their Bill of Materials (BoM).

While other tools were recognized as valuable, they were deemed to require broader organizational alignment and cultural change. As such, these tools were recommended for phased implementation alongside continued stakeholder engagement and data system improvements.

Sub-question 5: *What impact is expected from resolving the identified bottlenecks on NTS Hengelo's ROLT performance?*
Supporting sub-question 5.1: *What additional process or system changes are necessary to help NTS Hengelo consistently achieve the 90% ROLT compliance target?*

Chapter 6 assessed the performance implications of implementing fixed-cost pricing as the primary intervention. Using ALPHA V1 as a benchmark, where fixed pricing has already been adopted, clear improvements were observed: the average repair duration decreased from **61.5** days to **12.5** days (**an 80% reduction**), and ROLT compliance rose from **55%** to **94%**. These results demonstrate the effectiveness of standardizing the repair quotation process and eliminating administrative handoffs. A redesigned BPMN diagram confirmed that Steps 3 through 6, which previously accounted for 7% of unproductive time, were either streamlined or removed entirely under the fixed-pricing approach.

While similar improvements are expected for other recurring items analyzed in Chapter 5, a precise impact cannot yet be quantified. This is primarily due to limitations in ERP system usage, where hours are often not clocked or documented consistently, making step-level performance analysis infeasible.

To sustain and extend these improvements across the repair process, additional system and process changes are required. These include improving ERP logging compliance to enable data-driven evaluation, increasing internal awareness of the importance of repair process efficiency, and introducing visual dashboards to help cleanroom workers track and prioritize ongoing repair orders. Without addressing these supporting factors, even a well-designed fixed-pricing system may not fully realize its potential impact on ROLT performance.

Sub-question 6: *What tailored, evidence-based recommendations can be made to NTS Hengelo based on the findings from this research?*

Chapter 6 synthesized the findings of the research into a set of short- and long-term recommendations tailored to the operational context of NTS Hengelo. These recommendations aim to reduce repair order lead times and support sustained compliance with the 90% ROLT target.

Short-term actions, outlined in **Section 6.3.1**, are intended for implementation within the next three months. These include the immediate rollout of fixed-cost pricing for four high-frequency, low-variation item categories, the appointment of a designated process owner, preferably the repair coordinator, to monitor new repair orders for Bill of Materials (BoM) matches, and the launch of internal initiatives to raise awareness and improve ERP hour logging compliance.

Long-term actions, described in **Section 6.3.2**, are proposed for execution by early 2026. These involve integrating the fixed pricing framework into the onboarding process for new or high-growth items such as DELTA, conducting periodic reassessments of repair data using the bottleneck identification methods established in Chapter 3, and eventually introducing cleanroom visual dashboards to support repair prioritization, once stakeholder awareness and alignment have sufficiently improved.

Collectively, these recommendations are grounded in both empirical analysis and stakeholder input. They are designed to be practical, scalable, and responsive to the recurring inefficiencies identified throughout the study. While the adoption of fixed pricing represents an actionable near-term intervention, the long-term success of NTS Hengelo's repair process improvement efforts will depend on broader organizational changes related to culture, data discipline, and cross-departmental visibility.

7.2. Limitations

While this research offers valuable insights into reducing repair order lead times at NTS Hengelo, several limitations must be acknowledged. These limitations relate to the research timeline, data availability, methodological constraints, and the scope of implementation, all of which may affect the generalizability or completeness of the findings.

First, the short time frame of the research, approximately 10 weeks, restricted the ability to observe or measure the real-time implementation effects of the proposed solutions. For instance, the fixed-cost pricing framework, although validated and structured, was only partially operationalized during the study period. One item category (ALPHA V2) is actively undergoing implementation, whereas the remaining three item categories are still under internal review and pending coordination with Company X. As a result, the impact assessment relies primarily on retrospective data, stakeholder input, and observed performance from one previously standardized item (ALPHA V1), limiting the extent to which quantitative validation could be performed.

Second, the fixed-cost pricing analysis was based purely on financial patterns derived from invoice value, material quantity and cost, and estimated labor hours. The technical complexity of the repairs was not assessed in this framework. As such, items may appear similar in pricing structure yet vary significantly in technical execution difficulty, posing potential risks in fixed pricing without proper technical scoping.

Third, the reliability of ERP system data posed a significant constraint. Throughout the research, incomplete or inconsistent time logging was frequently encountered. Specifically, approximately 18% of the total 472 Company X repair orders lacked properly documented process steps, as detailed in **Section 4.2**. Additionally, for assessing the impact of fixed pricing on item ALPHA V1, no time data was available due to repair stakeholders not clocking in the hours after fixed-pricing was introduced. Similar data inconsistencies are highlighted in multiple sections. These gaps hindered precise step-level analysis and necessitated reliance on stakeholder interviews to confirm administrative delays, increasing the risk of subjectivity despite triangulation efforts. **Section 6.3** recommends strengthening ERP compliance to mitigate these issues in future practice through targeted training and awareness campaigns, ensuring consistent time tracking to support robust, data-driven evaluation.

Finally, the scope of the bottleneck analysis focused on six recurring repair items, representing 69 repair orders in 2024, approximately 37% of all active and complete repair orders (187) for that year. Although these items were chosen due to their recurring impact on ROLT performance, they do not reflect the full diversity of NTS Hengelo's high-mix, low-volume repair environment. The feasibility of fixed pricing depends on repair order similarity, particularly regarding the BoM. For items with few occurences, the proposed framework may be less applicable.

7.3. Future Opportunities

Building on the findings and limitations of this study, several opportunities for future research and improvement emerge. These opportunities span both operational and strategic dimensions and offer pathways to deepen the impact of the recommendations proposed.

First, a key area for further investigation lies in the longitudinal evaluation of fixed pricing implementation. While this study validated the feasibility of fixed pricing using historical data and item-level segmentation, future research could assess its performance once fully operational across the selected item categories. This includes measuring lead time reduction per process step, quantifying administrative time savings, and analyzing ROLT compliance trends over a longer period. Importantly, this would require consistent logging of repair hours within the ERP system, a foundational improvement also recommended in this thesis.

Second, the methodology used to identify and analyze bottlenecks (Chapter 3 and Chapter 4) could be reapplied in early 2026 to evaluate new repair order data from 2025. This follow-up analysis would serve two purposes: (1) to identify new recurring items that may emerge as bottlenecks, and (2) to determine whether the implemented solutions (e.g., fixed pricing) have reduced or shifted bottlenecks elsewhere in the process. Additionally, the process mining and Pareto-based analysis could be further enhanced with more granular ERP data and possibly combined with machine learning techniques to predict delays in advance.

Third, the categorization flowchart introduced in Chapter 5 could evolve into an automated decision-support tool. Integrating this logic into the ERP system would allow real-time classification of incoming repair orders based on BoM, enabling automatic quote selection and further minimizing administrative overhead. This would also improve internal transparency and reduce dependency on manual categorization by the repair coordinator.

Another promising area involves the development of visual tracking tools for cleanroom personnel. While stakeholder opinions were mixed during this study, future research could explore user-centered design approaches to prototype and test dashboards using tools such as Power BI, Odoo or several others each of which can connect to ERP systems. This would allow for real-time progress monitoring, improve visibility, and potentially reduce idling caused by communication gaps.

Finally, as highlighted in Chapter 6, a broader transformation of the repair process, using Business Process Reengineering (BPR) or similar strategic frameworks, may be appropriate once awareness and commitment to repairs increase across the organization. Future work could focus on designing and testing such holistic changes, incorporating cross-functional alignment, repair team restructuring, or incentive mechanisms to ensure that repair work receives sustained organizational focus.

7.4. Contribution to Theory and Practice

This research contributes meaningfully to both academic theory and practical application within the context of operational performance improvement in high-mix, low-volume manufacturing environments.

Theoretical Contributions

From a theoretical standpoint, this study reinforces the applicability of established frameworks such as Lean Thinking and Business Process Standardization (BPS) in administrative-heavy, non-repetitive repair contexts. While Lean has traditionally been applied to physical production lines, this research shows its relevance in streamlining information flow, reducing waiting time, and eliminating unnecessary approvals in a service-like setting. Specifically, the integration of Lean principles such as Continuous Flow into the repair quoting process illustrates how abstract lean tools can be effectively translated into administrative decision-making.

Additionally, this study contributes to the growing literature on repair process management, a less frequently explored domain compared to production. By combining quantitative bottleneck identification methods, such as Pareto analysis and ERP-based process mining, with qualitative insights from stakeholders, the study offers a robust mixed-method approach to diagnosing and addressing process inefficiencies in repair flows. This methodological framework may serve as a reference point for similar analyses in other service-oriented or repair-driven environments.

The research also highlights the strategic value of segmentation logic for standardizing pricing models in complex, low-volume repair environments. By introducing a BoM-based categorization flowchart, the study offers a practical and scalable method for grouping repair orders with similar cost structures. This approach enables consistent pricing even in irregular demand settings, helping reduce administrative overhead while maintaining pricing transparency.

Practical Contributions

On the practical side, this thesis provides NTS Hengelo with a structured framework to improve repair lead times and advance toward sustained ROLT KPI compliance. The BoM-based categorization flowchart introduced in this study not only segments repair orders by cost structure but also serves as a continuous tool to flag items eligible for fixed pricing. Combined with the fixed-pricing model, this approach reduces quotation delays, streamlines coordination with Company X, and offers a repeatable method for scaling pricing standardization across future repairs.

Furthermore, improving performance on the ROLT KPI has implications beyond operational efficiency. By enabling more timely and predictable repair cycles, NTS Hengelo may improve its supplier rating with Company X, strengthening its reputation and potentially leading to higher repair volumes in the future instead of relying on new builds. This shift reduces dependency on newly manufactured items and raw materials, thereby supporting broader sustainability objectives by extending product lifecycles and minimizing material consumption. In turn, this repair-focused approach not only enhances operational agility but also contributes positively to environmental outcomes. Thus, yielding societal benefits aligned with circular economy principles.

The development and visualization of the “future-state” BPMN diagram also provides tangible guidance for how fixed pricing can streamline process steps, eliminating administrative bottlenecks that accounted for 87% of the unproductive time in key process stages. These visual tools support internal alignment and can serve as templates for onboarding new employees or re-training current staff.

Moreover, the thesis identifies actionable short- and long-term recommendations grounded in both theory and stakeholder feedback. These include improvements in ERP data logging, the potential integration of visual dashboards using off-the-shelf tools, and a strategy for extending the fixed pricing model to new repair items.

Finally, by framing the research using the Managerial Problem-Solving Method (MPSM), this thesis demonstrates how structured problem-solving approaches can be adapted to complex industrial settings, combining systems thinking with stakeholder engagement and iterative validation.

In conclusion, this research bridges theory and practice by transforming abstract operational concepts into tailored, evidence-based interventions that address a real and pressing performance issue. It not only contributes to the operational excellence efforts at NTS Hengelo but also adds to the academic conversation around process optimization in service-like industrial operations.

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9. Appendix A

Sub-Research Question	Justification for Type of Research	Justification for Data Collection Method	Justification for Key Variables	Justification for Limitations
1. What KPIs, set by Company X, are currently used to evaluate the repair process at NTS Hengelo?	**Descriptive**: The goal is to document the predefined KPIs and expectations. **Qualitative & Quantitative**: KPIs are numeric, but qualitative data from interviews provide additional context.	**Company reports, internal documentation, interviews with NTS and Company X employees**: Official reports provide quantitative KPI values, while interviews offer qualitative insights.	**Repair process KPIs, Compliance benchmarks**: These define NTS Hengelo's repair performance evaluation.	**Potential bias in interviews** (employees may underreport internal issues)
2. What does the current repair process flow at NTS Hengelo entail? *2.1. How are different types of repairs categorized and handled within this workflow?*	**Descriptive**: This question maps out the existing process structure. **Qualitative**: It focuses on documenting workflows and repair categorization.	**Process mapping, interviews, company data analysis**: BPMN diagram visually represents workflows, while interviews clarify operational practices.	**Process flow steps, Repair categories**: Key components that define repair operations at NTS.	**Subjectivity in interviews** (process descriptions may vary across employees), **process may differ across departments** (lack of standardization).
3. What are the major bottleneck(s) in NTS Hengelo's repair process? *3.1. What structured methods can be used to identify process bottlenecks with the purpose of improving the repair process performance at NTS Hengelo?* *3.2. Which of these bottleneck identification methods are suitable for application to NTS Hengelo's repair process?*	**Exploratory**: The aim is to uncover unknown inefficiencies. **Qualitative & Quantitative**: Qualitative (interviews, literature), Quantitative (data analyses).	**Literature review, interviews, data analyses**: Literature offers theoretical insights; interviews & analyses provide real-world data.	**Bottlenecks, Process inefficiencies**: Essential for diagnosing issues in repair lead times.	**Limited existing research specific to NTS** (bottlenecks may not be well-documented), **potential bias in interviews** (employees may underreport internal issues).
4. What are the solutions to address identified bottlenecks in NTS Hengelo's repair process? *4.1. What structured methods can be utilized for resolving process bottlenecks to improve operational performance?* *4.2. Which of these bottleneck resolution methods are most suitable for application in the context of NTS Hengelo's repair process?*	**Exploratory**: Since multiple resolution methods exist, the study will explore which ones are best suited. **Qualitative& Quantitative**: The research relies on literature and expert input. Also, on different quantitative analyses.	**Literature review, interviews**: Literature helps compare bottleneck resolution methods; interviews and data analyses provide practical applicability insights.	**Bottleneck resolution methods**: The focus is on evaluating and selecting viable solutions.	**Applicability of methods to NTS may vary** (not all solutions may fit NTS), **difficulty in comparing methodologies** (varied effectiveness in different contexts).
5. What impact is expected from resolving the identified bottlenecks on NTS Hengelo's repair order lead time (ROLT) performance?	**Explanatory**: Establishes causal relationships between bottleneck resolution and	**Data analysis, interviews**: Performance data assesses improvement potential;	**Lead time improvements, Process efficiency gains**: Metrics defining the impact	**Assumptions on expected improvements** (forecasts may be speculative),

5.1. *What additional process or system changes are necessary to help NTS Hengelo achieve the 90% ROLT compliance target?*	expected improvements. **Qualitative & Quantitative**: Qualitative (interviews), Quantitative (data analysis).	interviews validate insights.	of bottleneck solutions.	**difficulty in quantifying certain benefits** (some benefits are intangible).
6. What tailored, evidence-based recommendations can be made to NTS Hengelo based on the findings from this research?	**Evaluative**: Focuses on assessing the best course of action. **Qualitative& Quantitative**: Recommendations are based on data, synthesis and expert validation.	**Synthesis of findings, expert validation, report formulation**: Consolidates findings into actionable recommendations.	**Feasibility of recommendations, Implementation impact**: The goal is to ensure practical solutions.	**Subjectivity in recommendation selection** (recommendations may be influenced by available data), **implementation constraints** (some solutions may be difficult to execute).

Table 9.1: Appendix A-1 Research Design

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Appendix A-2 – Use of AI

Artificial Intelligence (AI) tools were used to support the development of this thesis. The primary tool employed was **ChatGPT by OpenAI**, which was used to improve the clarity, structure, and readability of selected sections of the text. All content generated or revised with the help of AI was thoroughly reviewed and edited to ensure accuracy, relevance, and alignment with academic standards.

I take full responsibility for the final content and conclusions presented in this thesis.