IMPROVING THE END-TO-END PROCESS FLOW OF THE REPAIR SERVICE AT THALES NAVAL NETHERLANDS

Bachelor thesis

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Bachelor thesis Industrial Engineering & Management (IEM)

Improving the end-to-end process flow of the repair service at Thales Naval Netherlands

Publication date: October 26, 2021

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Preface

Dear reader,

In front of you is my bachelor assignment 'Improving the end-to-end process flow of the repair service at Thales Naval Netherlands'. This thesis has been conducted at Thales Naval Netherlands (TNNL) as finalization of my bachelor program Industrial Engineering and Management. The research focusses on improving the customer satisfaction by suggesting interventions in the repair service. During this research I worked at TNNL from April 2021 to August 2021.

Hereby, I want to thank all people who have supported me in the past few months. First, I would like to thank all employees of TNNL, especially Jos van den Bosch and Simon Huijink. Jos van den Bosch, who is Productmanager Service, made always time to meet and provided me with new insights to conduct this research. Simon Huijink, Service Designer of TNNL, gave me feedback where possible to apply my knowledge at TNNL. Next, I want to thank my supervisor Matthieu van der Heijden for always providing me with critical feedback and helping me to get the most out of my research.

Finally, I would like to thank my fellow students Naud Keen and Marnick Plomp for their feedback in the earlier parts of this research.

Gijs van Sambeek
Enschede, October 2021

Management summary

Thales Naval Netherlands (TNNL) designs, produces, and repairs radars, sensors, and combat management systems for the naval defence. This research is focussed on the service area of TNNL, the repairs. The repair service of TNNL faces a low customer satisfaction. To find a solution for the low customer satisfaction this research is executed. The following research question has been set up:

'How can TNNL improve the customer satisfaction by intervening the end-to-end process flow of the repair service at TNNL?

The research starts with the analysis of the current end-to-end process flow. The steps of the repair service are divided in four different phases:

1. The return merchandize authorisation (RMA) assessment phase: A defect product gets assessed if it should be sent to TNNL for a repair.
2. The request for quotation (RfQ) phase: TNNL sets up an offer including an expected lead time.
3. The order acceptance phase: The customer decides to accept or reject the repair offer.
4. The repair phase: TNNL repairs the defect product.

The RMA assessment is the shortest phase which takes up to two months, and the RfQ phase is the longest. The RfQ phase takes very long, from three months up to more than a year.

Next, a root cause analysis is executed to determine root causes of the low customer satisfaction. It became clear that root causes could be tackled by reducing the throughput times. This is one of the identified customer satisfaction indicators. Others are the information flow, the communication flow, and the delivery performance. The data analysis of the current repair service showed that the throughput times of the repair service could be grouped per customer group (customer has defect product), different supplier (supplies components for repair), and per specific product. Here, it became clear that interventions could be suggested based on the different customer groups since there is a significant difference. Repairs from the master customer group (72.5% of all repairs) encounter the least problems with a an average throughput time of 219 days, the investor customer group has the longest average throughput time of 627 days. There are no significant differences when analysing the different suppliers, and specific products.

To measure the impact of the interventions on the throughput times, a simulation model has been used. The repair process has been simplified to the three phases RMA application, RfQ, and order acceptance + repair to build a Monte Carlo simulation. The simulated repair service gave an output of an average throughput time of 277 days with a standard deviation of 167 days. The model has been proven valid, so the interventions can be implemented in this model.

The suggested interventions will be implemented for 9.0% of the repaired products, since this percentage is the amount of repairs in the top 10 most repaired products that have an average throughput time higher than 300 days. These repairs are requested by all three customer groups.

The first intervention is a loan-item. Here, for several products a loan-item will be sent to the customer when their defect product gets repaired. A repair with a loan-item skips the process after the RMA assessment, and decreases the non-operational time to a standard 60 days. The simulations showed a decrease to an average of 240 days. Providing loan-items is very easy to plan, so the overall on-time delivery performance would increase. Inventory costs are 25% of the cost price and depreciation costs between 5,000 euros and 10,000 euros. These are included in the original repair price without intervention, which is between 3,000 euros and 10,000 euros. If the repair costs exceed 60% of the cost price, the repair is not worth the costs. The advice from TNNL to the customer is to buy a new product. The repair price including a loan-item

increases to an amount between 14,250 euros and 32,500 euros. The cost price of items is between 25,000 and 50,000 euros which means that the repair price would be higher than 60% of the cost price most of the time. The decrease of throughput time of this intervention is not worth the costs.

The second intervention is inventory of components (from defect products). Here, for several products there is inventory on stock to improve the throughput time of these repair. When using this inventory the repair time decreases with a factor of 25%. The simulations showed a decrease to an average of 271 days. Promise dates would be more accurate because repair time is less unexpected, resulting in a higher on-time delivery performance. Inventory costs are 25% of the cost price of components and are included in the original repair price without intervention, which is between 3,000 euros and 10,000 euros. The cost price of components is 20% of the cost price of items. The repair price including inventory of components increases to an amount between 4,250 euros and 12,500 euros. The included inventory costs are 25% of the cost price of the components of a product per repair. This repair price never surpasses 60% of the cost price, so it will be worth the costs.

The third intervention is a fixed price for several products. Here, the RfQ phase will be skipped since there is no need to work out the actual costs of the repair. The price is determined beforehand and the customer has to decide whether to repair before TNNL makes any costs. Fixed price results in a better communication flow since the decision point of the customer agreeing on a repair is brought forward in the process. There are less cases where TNNL makes costs and the customer does not want a repair. A fixed price does also improve the information flow since the customer knows directly what costs are involved. When using fixed price, the simulations show a decrease to an average of 264 days. There is a risk where the incurred costs could exceed the paid fixed price due to cost fluctuations or obsolescence of components. The current repair costs vary between 3,000 and 10,000 euros. Due to the high variation of the repair price, this would mean that a fixed price should be close to 10,000 euros to minimize the chance of exceeding the fixed price. When TNNL finds out that a product cannot be repaired, they should buy a new product for replacement.

Based on the research and impact of the interventions, these are the recommendations:

- Organise more time stamps in the repair service than the current four time stamps. This made it difficult to indicate where the bottleneck in the process was situated. With more time stamps in the repair service, it would create a bigger insight in the different phases, and it would be possible to suggest a more specific intervention. The most important missing time stamp is the one separating the order acceptance, and the repair phase. Then, it would be clear how much time is spent in the repair phase. Next, I would suggest implementing more time stamps in the RfQ and repair phase. These are the phases where it is unclear what exactly causes delay in the process.
- The data analysis showed that some suppliers had really long throughput times. This is the result of the lack of supplier management. There are no agreements with suppliers about the lead time of repairs and the number of repairs. A recommendation would be to introduce supplier management and make agreements about lead times and number of repairs.
- Organize the repair process with the interventions fixed price and inventory of components for the repairs in the top 10 most repaired products that have an average throughput time higher than 300 days. In case of this research, this applies for items C, D, E, F, and G. However, nine out of ten of these items are obsolete and are a representation of items that will be repaired in the future. Exact amounts of inventory are therefore unknown. Both interventions show a decrease in throughput times, and could be implemented parallel. The fixed price should be set on average at 12,500 euros, and components of these items should be held on stock.

Glossary of terms

In Table 1, some terms and abbreviations that will be used regularly, are explained.

Table 1: Glossary of terms.

TNNL	Thales Naval Netherlands, corresponds to the part of Thales Netherlands responsible for the design, production, and service of maritime systems.
End-to-end process flow	The process flow of the repair service that starts at the point that a customer detects a defect in one of their parts from TNNL and ends when the defect part is repaired and delivered to the customer.
RMA	Short for return merchandize authorization; it is a code that is connected to a specific repair part in order to send back the repair part to the supplier.
CCC	Customer Contact Centre, which focusses on the contact with customers when they have a defect product.
RfQ (phase)	Short for request for quotation; starts when the customer applies for an RMA and ends when the offer for the repair has been composed by TNNL.
Repair (phase)	Starts when the customer accepts the repair offer and ends when the defect part is repaired delivered to customer.

Reader's guide

This thesis consists of five different chapters which will be shortly explained in down below.

Chapter 1 – Research methodology
In this chapter, the structure and approach of the research is covered. The chapter defines the problem context, after which it identifies the actual core problem. With this information the approach of the research is formed using research questions.

Chapter 2 – Analysing the current end-to-end process flow
This chapter describes the current situation of the repair service at Thales Naval Netherlands. A literature study describes four different customer satisfaction indicators, a business process model explains the process flow of the repair service, a root cause analysis elaborates on the many causes of the current problem, and a data analysis is performed based on the customer satisfaction indicator throughput time.

Chapter 3 – Modelling the current end-to-end process flow using data
After Chapter 2, there is a good basis for building a model of the repair service which is able to adapt interventions and value these based on the customer satisfaction indicator throughput time. Chapter 3 identifies a simulation method for this, it models the repair service, and it validates and verifies it.

Chapter 4 – Formulating methods for improvement
Chapter 4 proposes different interventions. It explains the interventions itself and explains what changes for the simulation. The results of these interventions are measured to see what impact these have.

Chapter 5 – Evaluating the improved concept
The final chapter evaluates the research. It elaborates the final conclusions, recommendations, and suggestions for further research.

After Chapter 5, the research will be substantiated by the literature list and appendices.

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1 Research methodology

This chapter presents the introduction of the company Thales, the encountered problem, and the research goal and design. The first section gives a clear overview of the problem identification. The second and last section will discuss the research approach which is based on the design science methodology by Wieringa (2016).

1.1 Problem identification

This section identifies the core problem of Thales Naval Netherlands' (TNNL) repair service. Firstly, it describes a general overview of the company Thales Group and Thales Netherlands. Then, it elaborates on the motivation behind the research, which answers the question: 'Why does TNNL see the opportunity for research?' The next subject describes the whole problem context, for example the cause-effect relationships between different problems. When this context is clear, the core problem and an insight in the norm and reality of the core problem become clear. At last, the intended deliverables will be explained.

1.1.1 Company introduction

Thales Group is a global leader in information technology and services, with a focus on digital and 'deep tech' innovations. Deep tech includes connectivity, big data, artificial intelligence, cybersecurity, and quantum technology. Defence, aeronautics, space, transportation and digital identity and security are the industries Thales Group operates in to provide solutions, services, and products for customers. The slogan of Thales Group is 'Building a future we can all trust', which emphasises the innovative mindset of Thales Group. They provide products to help their customers create a safer world. My bachelor assignment is executed at Thales Naval Netherlands (TNNL). Thales Netherlands is the Dutch brand of the international Thales Group and is located in Hengelo, Delft, Eindhoven and Huizen with approximately 2,000 employees. Thales Netherlands produces radars, sensors, and combat management systems for defence. Thales Netherlands originates from the company Hollandse Signaalapparaten (also called Signaal when it became part of Philips), that was taken over in 1991 (NEVAT, 2019). The naval department of Thales Netherlands is specialised in the naval defence.

1.1.2 Research motivation

Right now, the focus of TNNL is to maintain its status by obtaining a high-quality standard on service parts and repairs. However, the customer satisfaction of the end-to-end process flow of the repair service is low. The repair process starts with the customer who notices a defect in one of their parts from TNNL. At the end of the process, this defect should be repaired and the customer should be satisfied. But in some cases, it takes up to three years to complete this process and this results a negative customer experience. TNNL would like to improve this end-to-end process flow of the repair service in order to be more reliable for their customers. After all, the repair service is a process to maintain a good customer relationship.

1.1.3 Problem context

Thales Netherlands supplies to air, land, naval and joint forces. In this research, I will look at the naval repair service of Thales Netherlands. The end-to-end process flow starts when a ship of the navy has a defect on board and they correspond it to TNNL. It ends when the defect product is repaired and delivered to the customer.

Two years ago, customers filled in a customer satisfaction survey and the results were not very positive. All customers had the same complaints. Figure 1 shows the problem cluster of this situation. It visualises all different problems that TNNL and their customers encounter, and their cause-effect relationship. The low customer satisfaction is the action problem in this context. Heerkens & Van Winden (2017) describe an action problem as a discrepancy between the norm and reality. The reality is the low customer satisfaction, the norm is a higher customer satisfaction that is measurable by customer satisfaction indicators.

To identify the problems in the repair service at TNNL, I interviewed five important roles in the repair service (see appendix A for an explanation of the important roles). These interviewees are all part of the organization of TNNL, representing different perspectives of the repair service. However, a limitation of this method is that interviewing only people within the repair service does not give a complete overview of all problems and their causes. When the answers contradicted each other, I discussed it with the supervisors of TNNL who have an overview in the repair service to decide which problems related to each other. After the interviews, I created a problem cluster (Figure 1) that ends with the action problem *'Low customer satisfaction'* in the red box. I will explain this cluster following a clockwise route in appendix B.

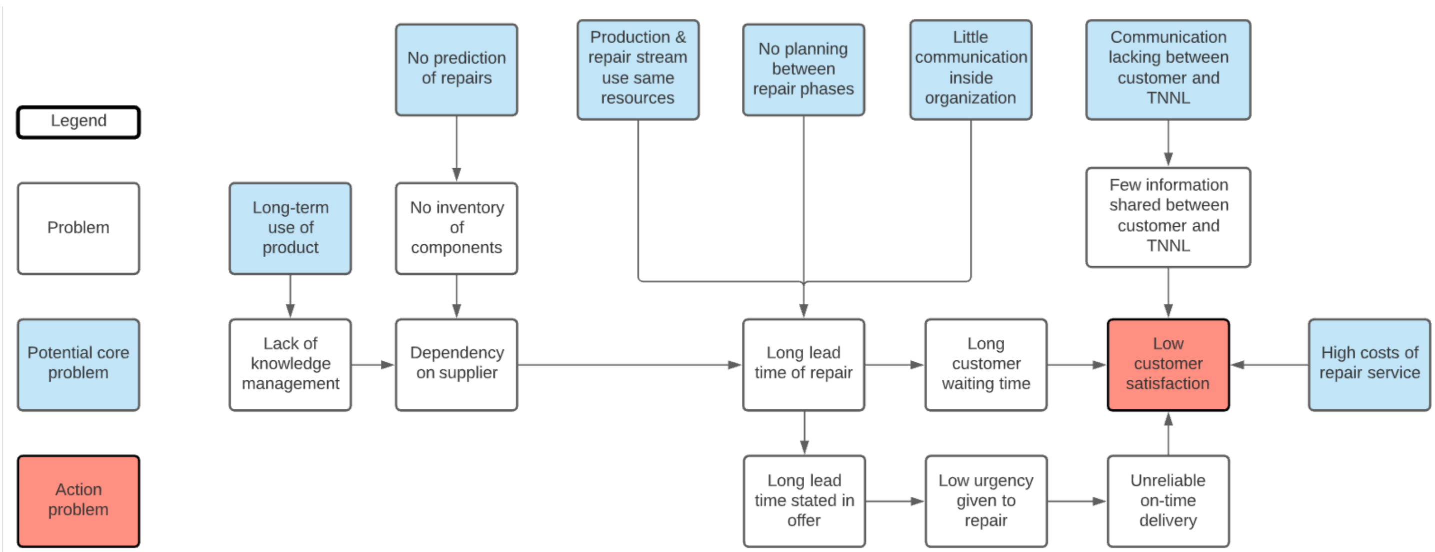

Figure 1: Problem cluster of all detected problems and their cause-effect relationship.

1.1.4 Core problem

To find the core problem Heerkens & Van Winden (2017) state the following approach:

1. Start at the last problem in the problem cluster that does not have an effect and go back to the problems that do not have a direct cause themselves. These problems are potential core problems, list those problems.
2. If one the problems is non-influenceable, the problem cannot be a core problem, remove those problems from the list.
3. If more than one problem remains, make an educative guess which would have the highest impact at the lowest costs when solving it.
4. One problem remains, the core problem.

When evaluating the Subsection 1.1.3, there are different problems that do not have a direct cause themselves. These are the potential core problems: *'High costs of repair service'*, *'Long-term use of product'*, *'No prediction of repairs'*, *'Production & repair stream use same resources'*, *'No planning* *between repair phases'*, *'Little communication inside organisation'*, and *'Communication lacking between customer and TNNL'*. Figure 1 shows potential core problems within the light blue boxes.

The next step is to remove the non-influenceable problems. In this context, *'Long-term use of product'* cannot be influenced due to the fact that TNNL builds products that are supposed to last the entire lifetime of a ship of the navy. This problem is removed and two potential core problems remain.

The third step is to make an educated guess which remaining problem would have the highest impact at the lowest costs when solving it. The 'cost' problem is not the problem with the highest impact, since *'High costs of repair service'* is not a big problem according to the survey that customers did fill in. The costs just do not represent the expectations of the customer about the repair service. The problem which fits this description is a combination of the upper five problems. These problems have high impact because solving them would benefit the whole end-to-end process flow and its problems. Besides this, an end-to-end improvement is preferred, because most small internal improvements of the last years have not led to a structural improvement of the repair service.

The problems *'No prediction of repairs'*, *'Production & repair stream use same resources'*, *'No planning between repair phases'*, *'Little communication inside organisation'*, and *'Communication lacking between customer and TNNL'* can be combined as core problem *'Non-optimal end-to-end process flow'*.

1.1.5 Norm and reality core problem

Currently, the problem is a non-optimal end-to-end process flow of the repair service. The reality is that this process does not work smoothly, and customers are not satisfied based on the problems described in Subsection 1.1.3. Communication, information, and organizational flows are not efficient or clear to employees. To quantify this, the reality is a throughput time that is in some repair cases up to two to three years. This situation is not preferable. The norm is that there should be an improved end-to-end process flow of the repair service, resulting in a throughput time that does not exceed the promised throughput time. About this promised throughput time there is a lot of discussion within TNNL. What should this norm be? Based on my educated guess, this promised throughput time is below a year.

1.2 Problem solving approach

With a clear overview of the problem context, the next step is to formulate an approach for the research. This section describes the approach based on the design science methodology from Wieringa (2016) This is a stepwise approach and every step I will elaborate with a research question that will be answered. The research questions will be divided in the following steps:

- Describing the current end-to-end process flow
- Modelling the end-to-end process flow using data
- Formulating methods for improvement
- Evaluating the improved concept

When following these steps, the main research question *"How can TNNL improve the customer satisfaction by intervening the end-to-end process flow of the repair service at TNNL?"*, can be solved.

1.2.1 Describing the current end-to-end process flow

The goal of this research is to deliver a clear overview of the end-to-end process flow of the repair service. With this clear overview, problems in the end-to-end process flow can be solved and the customer satisfaction will go up. The description of the current end-to-end process flow contains semi-structured one-on-one interviews with employees (important roles within the repair service) of TNNL and literature study. The interviews will give an overview of the internal and external processes that are involved in the repair process. The literature study will contribute to modelling this process. The research question to solve in this stage of the design science research methodology, is the following:

1 What is the current situation of the end-to-end process flow?

a. What are the indicators of customer satisfaction?

b. What stakeholders do I need to speak in order to create an overview of the current situation?

c. How can I model a clear overview and the flows of the current repair service?

d. Which data could be used for the overview of the current repair service to quantify this current situation? And how to give an overview with this data?

To solve this research question, a few steps are set up. First, I will do a literature study on customer satisfaction indicators. I will also identify the important roles within the repair service who can give an overview of the current situation from different perspectives. Next, I will conduct qualitative interviews with those important roles about the repair service. This will be a sample size of approximately 10. With the information gathered, I need to know how to model this and I will do a literature study. If it is clear how it should look, I need to figure out what data to display. This data should include historical data of the past five years. I will gather this by contacting the data analyst specialised in the repair service. In the end, the overview can be constructed, visualizing the current end-to-end process flow of the repair service at TNNL without considering the costs.

1.2.2 Modelling the end-to-end process flow using data

The next phase in the research will be to find a way to model the current end-to-end process flow. The research question and sub-questions corresponding to this phase are:

2 What does the modelled current end-to-end process flow look like using data?

a. Which methods are present to model the data of the repair service?

b. How do I use this method to model the data of the repair service?

c. Which assumptions do I have to make to make the model work?

d. Can I verify and validate the model?

In order to find out how interventions would influence the repair service a model has to be built. By means of a literature study, I will find out what method to use when building a model to visualise data. Next, all input has to be collected to build the actual model. This input will be quantitative, it will be the historical data of the past five years. When building this model, it could be possible that there is a lack of information. I need to set up assumptions to fill those gaps in the model. Eventually, after building the model, it should be possible to verify and validate it.

1.2.3 Formulating methods for improvement

The third phase of the research is to find the improvements to implement in the end-to-end process flow. The research question corresponding to this phase has three sub-questions.

3 Which interventions are possible for an improved concept?

a. Which interventions are available to improve the current end-to-end process flow?

b. Which improvements have the biggest positive impact on the customer satisfaction at the lowest costs?

With the constructed model, it is possible to see what effect different interventions have. Eventually, it should be possible to recommend some interventions. I will suggest interventions based on the meetings with the supervisors of TNNL and the interviewed important roles. When suggesting interventions, a consideration between costs and benefit (customer satisfaction) should be made to make the intervention quantifiable.

1.2.4 Evaluating the improved concept

When the improvements are compared, it is time for the evaluation and conclusion of the research. An additional research questions corresponding to this phase is the following:

4 What should TNNL do to increase the customer satisfaction based on the interventions?

The subjects that need extra research are also important. This way, it is clear that the next steps are explored.

1.2.5 Intended deliverables

Deliverables within my research questions are a root cause analysis of the core problem, a business process model of the current repair process, a list of possible improvements for the repair process with costs and benefits, an improved concept of the repair process with additional key performance indicators of the customer satisfaction and finally the recommendations. Together with the supervisors of TNNL, I have also discussed the possibility to create a tool which quantitatively analyses the repair service based on the present data. The result of this discussion is that the design of such a tool is not my main goal.

2 Analysing the current end-to-end process flow

In this chapter, the question "How can I give an overview of the current situation of the end-to-end process flow?" will be answered. This process is about the repair service at TNNL. Repair service is installing, maintaining, repairing, replacing, testing, inspecting or modifying for compensation, or under a warranty of electronic appliances (Law Insider, 2021). In case of my research, these electronic appliances are the radars, sensors, and combat management systems of TNNL. To support the answer to my research question, I identify the stakeholders in appendix A. In this chapter, I elaborate on the indicators of customer satisfaction, I model the repair service, I analyse the root causes, and I analyse the data of the repair service.

2.1 Customer satisfaction

Customer satisfaction is very important in my research. The action problem in this research is *"low customer satisfaction"*, but what is this customer satisfaction? And more importantly, how can we measure it, and how can we measure improvements in customer satisfaction?

Basically, customer satisfaction includes the factors that correspond to the customer's needs (Kuronen & Takala, 2013). Examples of these needs could be professionalism, conformity, or could be related to delivery time and price. Customer satisfaction is essentially a strategy for achieving product competitiveness (Dos Santos & Harland, 2012). Therefore, the product design process is very important. This is in the case of my research, the design of the repair service.

2.1.1 Customer satisfaction indicators

Lombardo et al. (2018) highlight that there are in general five key aspects of customer satisfaction. These aspects are tangibility, responsiveness, assurance capacity, reliability, and empathy. However, they also write that not all of these qualities are representative in the service industry. The subject of their paper is public transport service, and therefore they convert the key aspects to accessibility, assurance capacity, safety, cleanliness, and timeliness. Next to these aspects, they define items/variables for each of these key aspects to make them quantifiable.

In the survey that was sent to the customer two years ago, the complaints were based on the topics costs, on-time delivery (OTD), lead time, communication flow, and information flow. When choosing the customer satisfaction indicators, we have to look at the general key aspects that Lombardo et al. (2018) describe and try to personalise these to the situation of the repair service of TNNL.

- Tangibility is about the transparency of the process and can be linked to the extent of information flow between the customer and TNNL. If there is more information shared, there is more transparency.
- Responsiveness is the extent to which the customer receives response and the way how TNNL responds, which correlates to the extent of communication flow between the customer and TNNL.
- The third aspect is assurance capacity and refers to trust and precision of employees. Lead time is among other things a derivative of the trust and precision of employees to execute a repair. Therefore, I have decided to quantify assurance capacity with lead time of the repair service.
- Reliability is the aspect that represents if the expectation is similar to reality. Therefore, on-time delivery links to reliability.
- The last key aspect of customer satisfaction is empathy. This factor was not encountered in the survey about customer satisfaction, so it will not be taken into account as indicator

To conclude, the four indicators of customer satisfaction are the extend of information flow, the extend of communication flow, the lead time, the reliability (OTD).

2.1.2 Measurement customer satisfaction

The aspects that the customer highlights as feedback to improve the repair service are the communication flow, the information flow, the lead time, and the on-time delivery. In this research, I will make recommendations about the repair service with the goal to improve the customer satisfaction. The four aspects above are indicators for the customer satisfaction. To propose improvements for the repair service, I need to know if these influence my indicators.

Communication flow

To quantify the communication flow, it is important to know what is meant with the communication flow. Lunenburg (2010) describes four different dimensions of communication; upward, downward, horizontal, and external communication. Upward, downward, and horizontal communication are about the internal communication within a company. Meanwhile, external communication is about communication flows between the company and a variety of stakeholders outside the organisation. In case of this research, the communication flow of the repair process consists of the communication between the customer and TNNL. To quantify this flow, the number of contact moments could be measured.

Currently, there are contact moments where TNNL assesses whether it is possible to repair the defect product and whether this would fit the budget. The results of this assessment are communicated with the customers. After these moments, TNNL composes an offer for the repair, if the customer agrees on the financial terms and duration of the repair, they can place an order. These moments take place before the actual repair, when the repair is in progress, there are no additional communication flows where it could be decided to continue or stop the repair.

During the process of the repair, there are only updates for the customer when the promise date will be postponed. There are no other updates about the offer or repair.

To conclude, there are 2 big communication moments. More or changed contact moments would make the process more responsive; this could mean an improvement of the customer satisfaction. This flow is changed when implementing the intervention proposed in Section 4.3. However, this is not an indicator that can be operationalized in a data analysis, so it will be left out.

Information flow

The information flow is about the completeness of information shared between the customer and TNNL. When the customer applies for an RMA, it is important for TNNL to know as much as possible about the defect, and on the other hand does the customer want as much information as possible about the repair.

Information flow corresponds to communication flow since communication is the way to transfer information. Right now, TNNL often receives too little information from the customer for immediate action. This results in an extra step in the repair process, the inspection of the repair part at TNNL. Another aspect of the information flow is the lack of knowledge of the customer about the status of the offer or repair. There are no information flows in the repair service explaining the status of an offer or the repair.

To make the information flow quantifiable, a checklist of information needed should be made for every step in the repair process. When there is lack of information at a step in the process, this step will not be checked. This data can be analysed to see if TNNL makes any improvement in the customer satisfaction indicator information flow. Right now, this is not an indicator that can be operationalized in a data analysis, so it will be left out.

Lead time

The lead time of the repair service is the duration of time that starts when the customer accepts the repair offer and ends when the defect part is repaired. In some cases, this process takes up to three years. From the obtained data, the average lead time could be derived. This showed a lead time of approximately 270 days.

On-time delivery
To see if TNNL is reliable, we take on-time delivery as an indicator. This indicator shows a percentage that the repair is delivered within the promised time. However, this is somewhat harder to obtain. TNNL set a promise date in their offer when they predict to finish the repair and communicates this with the customer. This way the customer can plan its activities in advance. However, there could appear unforeseen problems in the repair process, and TNNL postpones their promise date based on these problems. This results in an on-time delivery based on a promise date that could be postponed during the repair process. Therefore, their on-time delivery is not very reliable to indicate the real on-time delivery performance and will be left out as indicator.

2.2 Process model

To solve the research question *'How can I model a clear overview of the current repair service?'*, the literature describes different ways of modelling a process. In appendix C, I compare these methods of modelling and finally I select one method. The conclusion of this literature study is to use business process modelling notation (BPMN) to model the current repair service. BPMN is the most inclusive and detailed method of modelling. This fits the complex repair service of TNNL very well. It can visualise the context of activities in pools and lanes, which can represent the different departments of TNNL. In appendix C, I give an extensive explanation of this method. In this subsection, I will explain the process flow of the repair service at TNNL, which is constructed with help of the important roles within the repair service at TNNL.

2.2.1 Business process model

I use BPMN to model an aggregated level of the repair service, also called the high-level process. In this model, the information and material flows are visualised, just like the important decisions of the repair service within TNNL's organisation.

Figure 2 shows the business process model of the theoretical end-to-end process flow of the repair service at TNNL. In practice, not all repairs will follow this exact route. This will differ when repairing under warranty or under contract. But this is outside the scope of this research because there is no data of these cases.

The process starts when the customer contacts the Customer Contact Centre (CCC). This is also where the RMA application starts. After an approval of the CCC, the repair part can be sent to TNNL. When the repair part enters TNNL, the repair process can be split up into two phases: request for quotation and the repair itself. In the first phase, the repair part gets inspected. The phase starts with the arrival of the repair part and questions like, "What is wrong with the product?", "Are we able to fix it?", and "How long and expensive is the repair going to be?" are answered and communicated with the customer in this phase. The phase ends when TNNL has set up an offer for the customer.

After the order of the customer, the phase of the actual repair starts. This is a start sign for the internal or external repair (at the supplier). This phase ends when the repair is succeeded and the repaired part gets send to the customer. The repair process is finished and the customer has a repaired product.

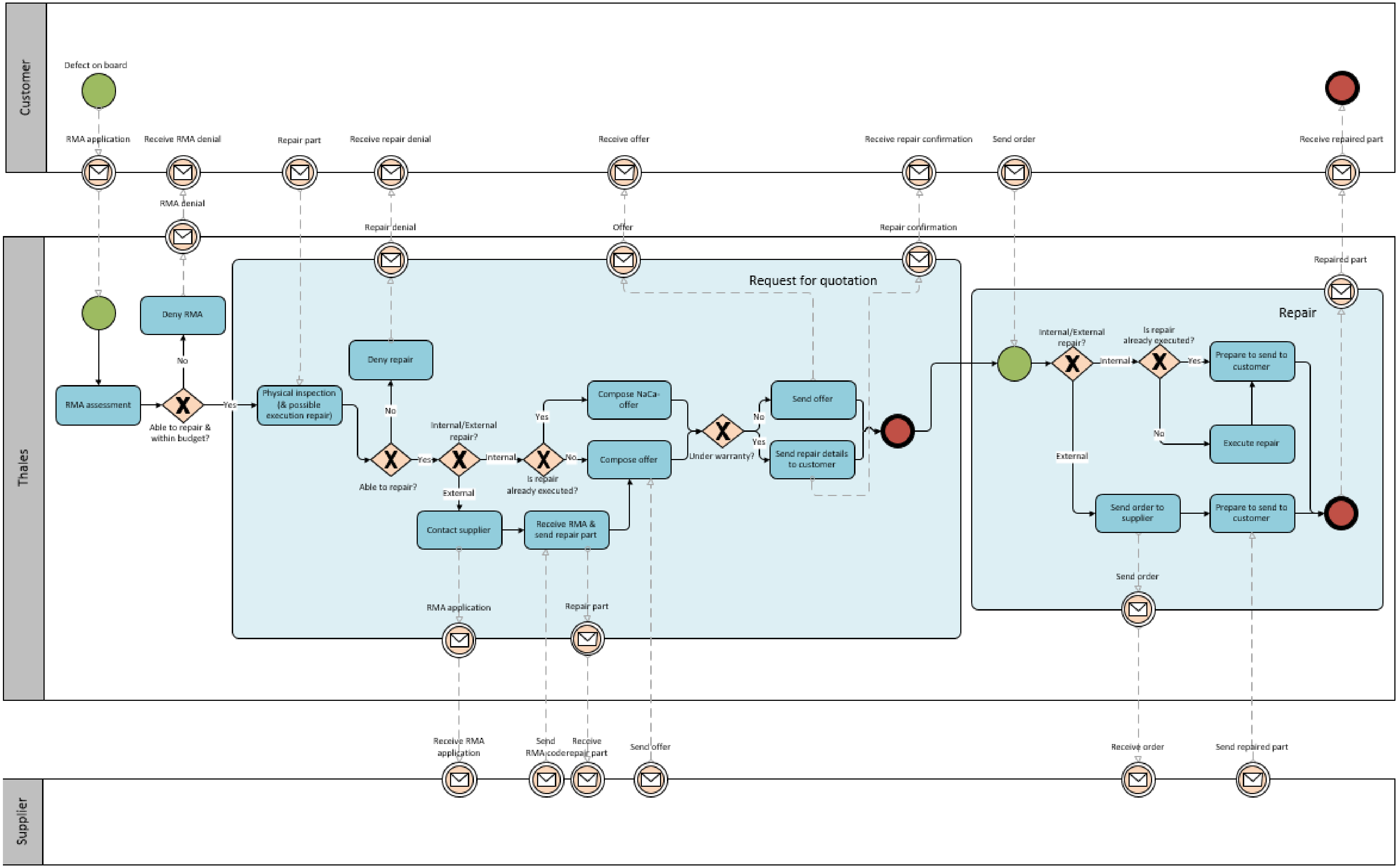

Figure 2: Business process model of the repair service

2.3 Root cause analysis

Next to my problem cluster, which I created in the chapter *'Research Methodology'*, I have decided to create a more extensive overview of the problems occurring in the repair service of TNNL. This is an elaboration on the problem cluster in Figure 1. I will do this by performing a root cause analysis (RCA) on the current situation because it provides a structured framework to identify the root causes in the process. In the project, TNNL is doing parallel to my research, they will also perform this analysis. More specifically, they will use a fishbone diagram to find the root causes. That is why I have chosen to use another method to find the root causes, and this method is the 3 x 5 why's technique by Gangidi (2019). This technique is explained in appendix D.

2.3.1 Repair service RCA

When implementing the method described in appendix D, the diagram in Figure 3 is created.

Because of the complexity of the context of the repair service at TNNL, I have adjusted the 3 x 5 why's technique. The first thing that is different is the separation of one why into two answers. In some cases, answering the question why, did result in two answers. Besides this adjustment, I have also decided to move away from the original three classes of the 3 x 5 why's technique. Instead, I identified the classes perception, culture, and process that correspond to the why's of the action problem *"Low customer satisfaction"*. These classes contain more than just the problems that can be measured. These are about the 'soft' side of the customer satisfaction.

Perception is about the soft part of the customer satisfaction. The part which cannot be measured, but which is very important for the feeling of the customer. It is about transparency and the feeling of the customer that they are heard by the service-providing organisation. Arasli (2009) describes that service quality is an important antecedent of customer satisfaction and this is influenced by perceived value. *Culture* is a more abstract class. The problems about the culture of the organisation, their behaviour towards the customer is classified under this term. *Process* is about the measurable problems that, combined with the other classes, cause the low customer satisfaction.

The root cause analysis contains elements from the problem cluster in Figure 1 and the customer satisfaction indicators of Section 2.1. These are the few information shared between the customer and TNNL, the communication lacking between the customer and TNNL, the long lead time of a repair, and the unreliable on-time delivery performance. The conducted interviews with important roles within the repair process (Appendix A) provided root causes to the action problem. In appendix E, the identified root causes are explained which have a red outline in Figure 3. The most important root causes are:

- The current repair service is a reactive instead of a proactive service
- Decisions are not made on the right level of organization
- There is lack of criteria on repairs entering the repair process.

This results in the high throughput times since TNNL sees every repair order as unique case and there is no structural management within the organisation. However, not all root causes are applicable for this research. To quantify possible improvement for the repair process, this research will focus on the measurable problems regarding throughput times. This way an improvement can be measured, and it will benefit the repair service and thus, the customer.

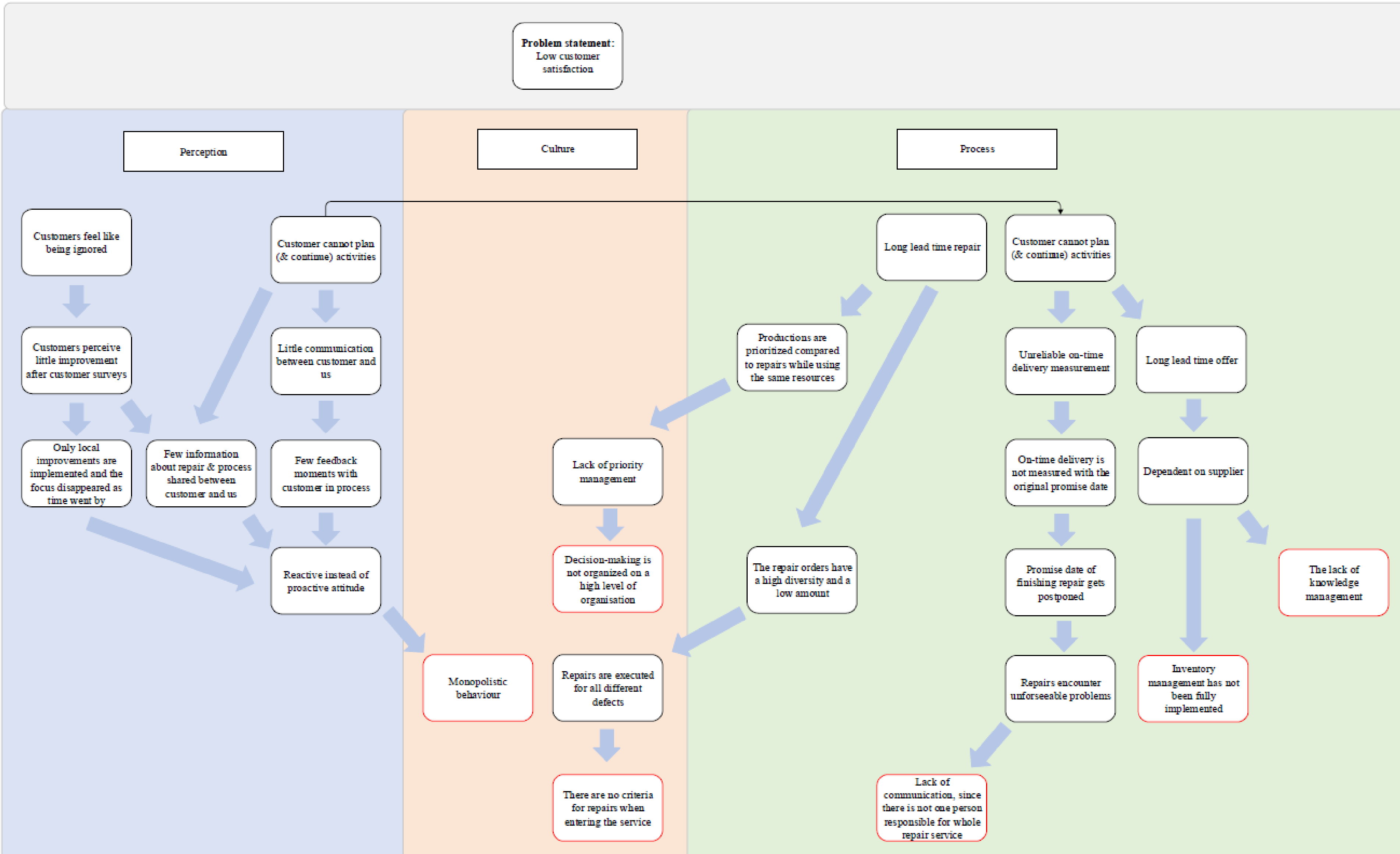

Figure 3: Root cause analysis of the repair process

2.4 Data analysis

To get a clear overview of the current situation, data has been analysed. The first topic is that there is need for a simplification in the process model. Another thing to keep in mind are the different customer groups. At last, there is differentiation on make or buy products, repairs involving a supplier, and differentiation based on item code. The differentiation is analysed to see how the throughput times relate to the different customer groups, products, and suppliers. The other customer satisfaction indicators are not taken into account, since there is no clear data of those.

2.4.1 Dataset

The data of the dataset used, consists of repair orders of the previous 5 years. The size of this dataset is 2251 repair orders. These repair orders consist of the following information:

- The customer
- Whether it is a make or buy product (will be explained in Subsection 2.4.4)
- The item code (product number)
- The supplier of the product
- The throughput times of different phases (phases will described in Subsection 2.4.2)

2.4.2 Simplified process model

As previously mentioned, the repair service can be split up into different parts. This is made visible in the business process model. I have created a simplified process model to quantify the throughput times. This is built with the RMA assessment, RfQ, order acceptance and repair phase. Figure 4 shows the simplification of the repair service per phase. It shows that a repair order could follow two paths, one where the repair gets executed after the order acceptance of the customer, and one where the repair already starts before an offer is send to the customer. The X/Y ratio is about the repair orders with an RfQ without repair (X%) and the repair orders with an RfQ including repair (Y%).

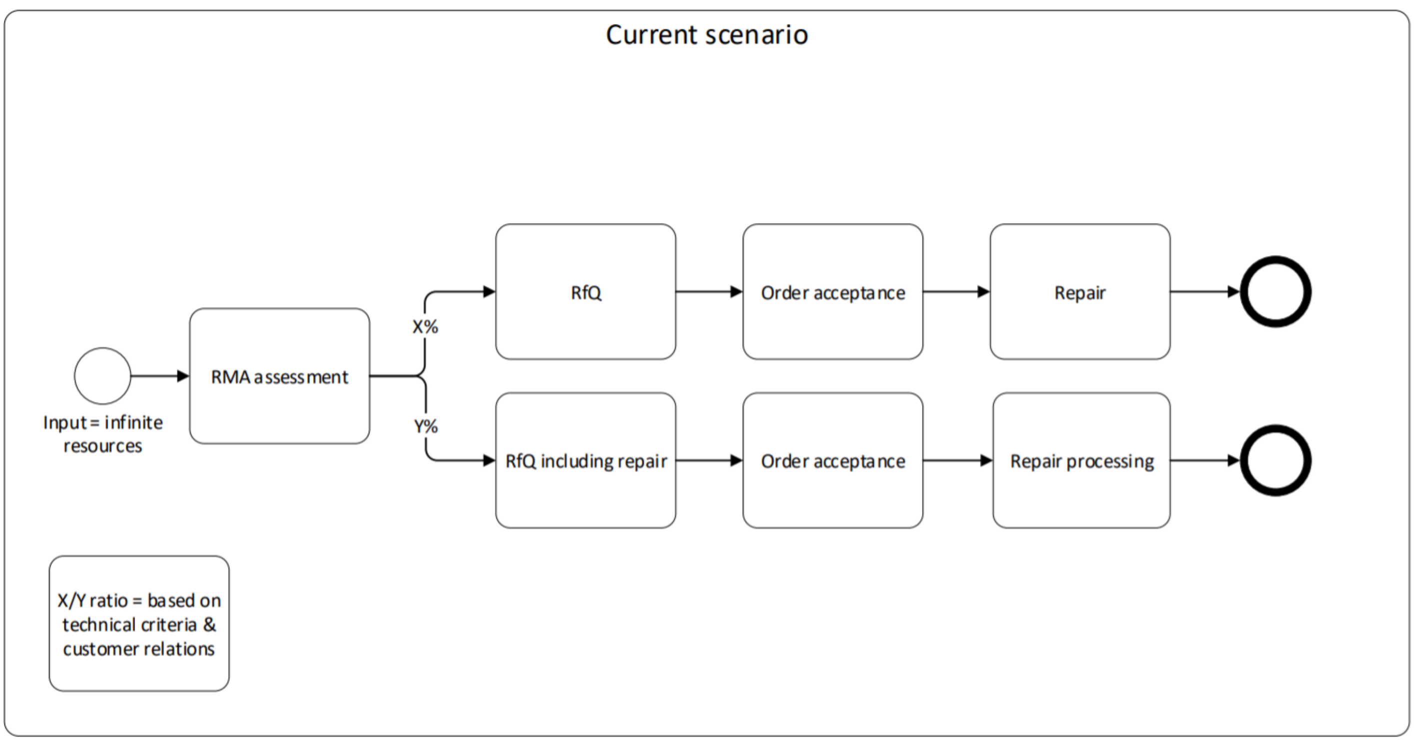

Figure 4: A simplified model of the repair service

These phases are explained as follows:

- RMA assessment: This is the phase from the moment that the customer gets into contact with TNNL to report a defect, until the moment that TNNL receives the repair part. The RMA application could be denied if the expected costs of the repair exceed 60% of the purchase price of the product. However, this is not included in the research since these cases are not taken into account as repair order and interventions would not influence these cases.
- Request for Quotation (RfQ): This phase starts when TNNL receives the repair part and ends when TNNL sends an offer to the customer. Within this phase, it could be possible to already execute the actual repair, but this variable is customer-specific (X/Y ratio). When including the repair in the RfQ phase, the offer will be composed after making costs for the repair. This way TNNL is more precise about the price, however this creates the situation where the product is repaired before an offer acceptance of the customer.
- Offer acceptance: This is the phase from the moment that the customer receives the offer, until the moment that the customer accepts the offer. An offer could be denied, but this is not included in this research, since these cases are not considered as repair order and interventions would not influence these cases. This is the same as in the situation of the RMA assessment phase.
- Repair (processing): The phase starting when the customer accepts the offer and ending when TNNL finishes and sends the repaired part to the customer. In case the repair order follows the path where the repair gets executed in the RfQ including repair phase, this phase is different and takes less time. The repair is executed, so final phase is to process the repair to send it to the customer.

The analysed data did not provide many time stamps of the repair process. It was very hard to find many data on the throughput times. After the analysis, four different time stamps, resulting in three different phases with their own throughput times, were found. Because of the lack of time stamps, the order acceptance and repair phase cannot be two separate phases. Therefore, these two phases are merged. A new current process model is created for this change, visualised in Figure 5. This shows three phases: the RMA assessment, the RfQ, and the order acceptance + repair phase.

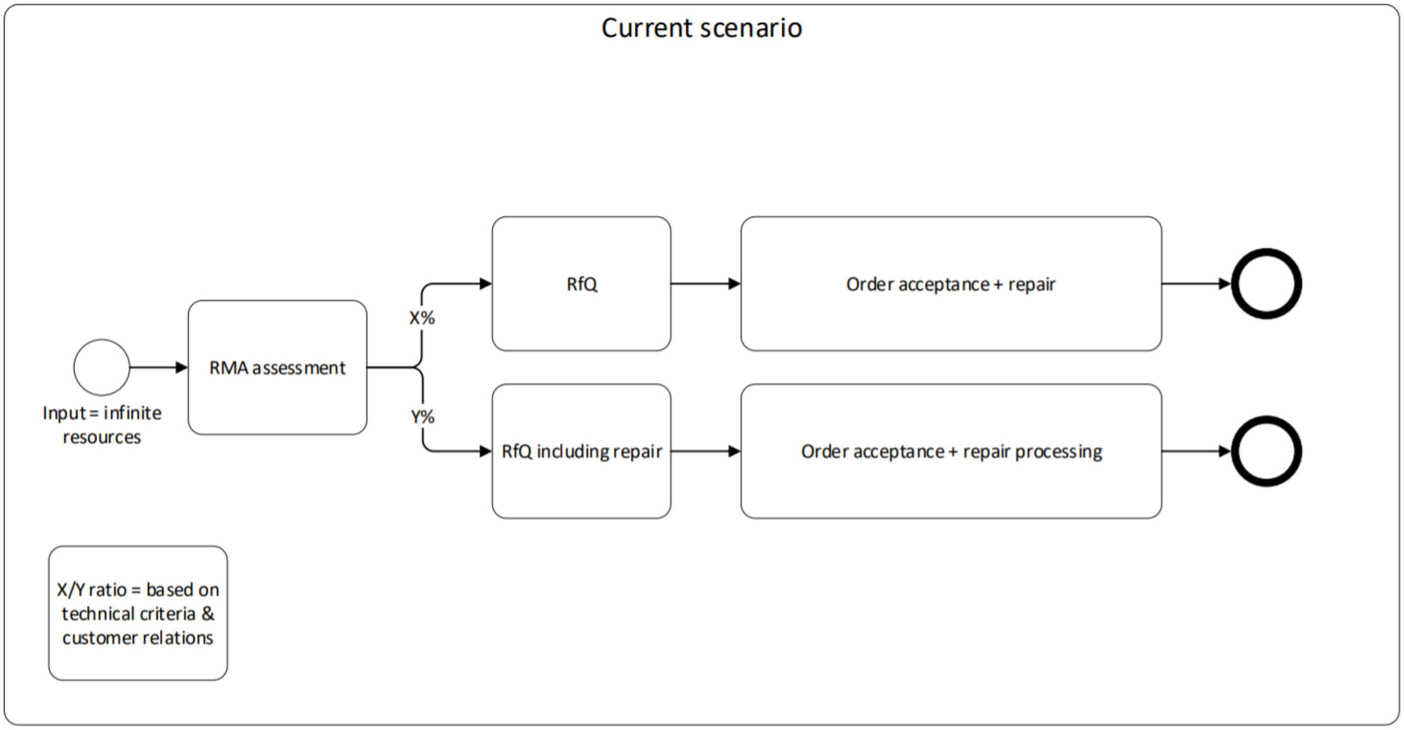

Figure 5: The process model of the current repair process based on the present time stamps.

2.4.3 Customer groups

TNNL has different customers. These customers behave in different ways. To categorise these customers, TNNL organised four different groups (shown in Figure 6):

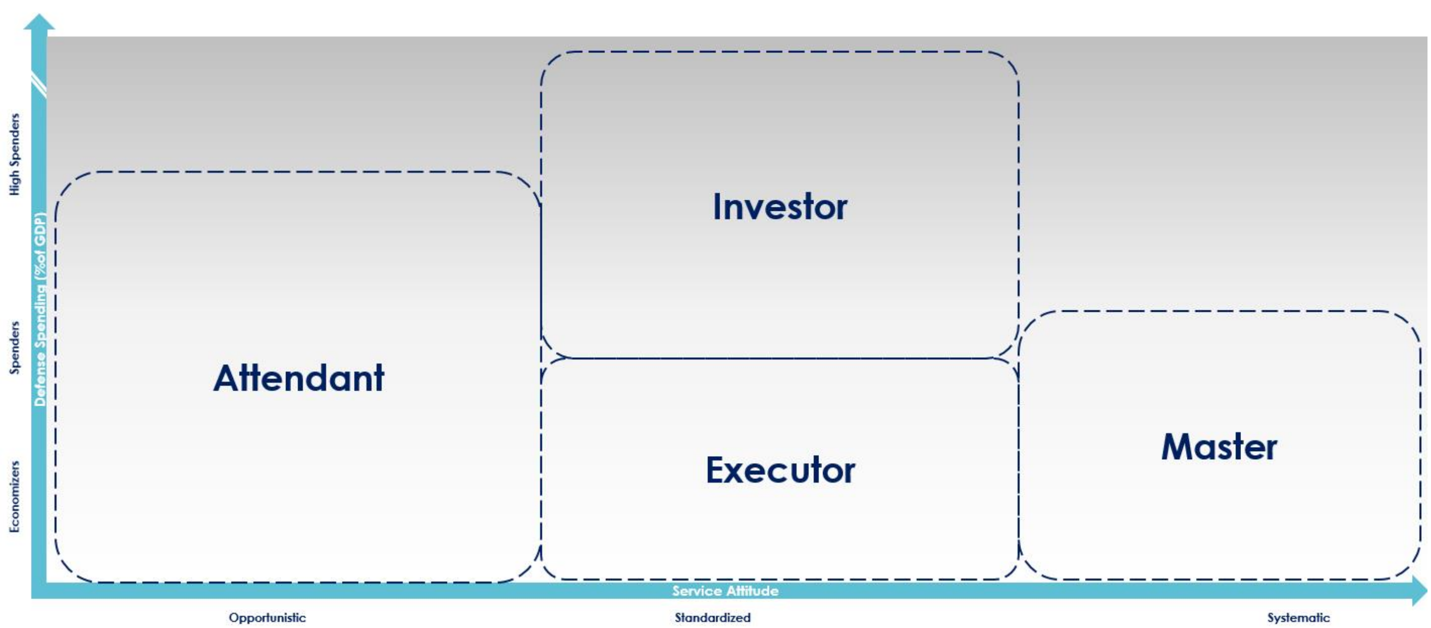

Figure 6: The four customer groups visualised based on their behaviour.

- The master: This group works the most systematic when preparing a repair. They keep budget for a repair, so when they send a defect product to repair, they can make a repair order. That is why TNNL starts earlier with executing the repair than repairs for other customers. Hundred per cent of the repairs are following the repair path with RfQ including repair (Y=100%), meanwhile for other customers this is ten per cent (see Table 2).
- The investor: This customer spends a lot of money on the newest products and repairs, however clear agreements have to be made about information and communication, because they work less systematic as the master customer group.
- The executor: This group is a midway between the master and attendant group. They are similar to the investor customer; however they cannot spend a lot of money on the newest products and repairs. Because they also work less systematic as the master customer group, this group needs more attention.
- The attendant: This group works the most opportunistic when preparing a repair. There are cases where they order something and end up with no budget.

The way these customer groups differ in behaviour becomes visible in the ratio of RfQ including or excluding repair, and therefore in the data of the throughput times. These groups have each their own distribution of the RfQ phase and the order acceptance and repair phase. The division of the customer groups is 72.5% master group, 2.0% investor group, 20.4% executor group, and 5.1% attendant group.

To create a complete data analysis, it would be ideal to have data of all different groups. However, the fact is that there is a lack of data within the attendant group. Therefore, it is impossible to include this in the data analysis. Besides the attendant group, there is the investor group which is involved in only 2.0% of all repair orders. There is data available of this customer group but how reliable is it? This is a good question and the investor group could be excluded because of the few data, however it is important to include as much data as possible for further research. When suggesting interventions the investor group should be included.

This leaves three customer groups; the master, the investor, and the executor group. The data about these groups showed the following information in Table 2 and Table 3. This data is based on one representative country per customer group.

Table 2: X/Y ratio of the customer groups.

Customer group	**RfQ excluding repair (X%)**	**RfQ including repair (Y%)**
Master	0%	100%
Investor	90%	10%
Executor	90%	10%

Table 3: Mean and standard deviation (in days) of different phases in the repair service per customer group based on data.

	Customer group	**RMA assessment phase**	**RfQ phase**	**Order acceptance + repair phase**
Mean of throughput time (days) repair service	Master	42	99	78
	Investor	45	338	234
	Executor	63	-	261
Standard deviation of throughput time (days) repair service	Master	64	43	97
	Investor	49	290	117
	Executor	70	-	153

One interesting thing in Table 3 is the lack of outcomes of the executor group in the RfQ phase. There, the mean throughput time is not present. There is a no data about this group in the RfQ phase, so an assumption has been made based on an expert opinion. This expert opinion gave random throughput times between the 60 and 120 days. This means a mean of 90 days for the executor group in the RfQ phase. However, this is lower than the master group in the same phase. The repair process runs most smoothly for the master group, so a mean of 90 days for the executor group is not realistic. It should be at least 99 days according to the data of the master group. And that is why I assumed the mean and standard deviation of the executor group to be equal to the mean and standard deviation of the master group (respectively 99 and 43 days, see Table 4).

Another point of interest is that in the RfQ and order acceptance + repair phase, the master group has lower outcomes than the investor and executor group in both cases (except for the executor group in the RfQ phase). That is because of the behaviour of the master customer group and they have a systematic service attitude resulting in faster response in actions. Even though the master group has 100% of the time an RfQ phase including repair, this throughput time is lower. This RfQ including repair phase is much shorter because the offer is composed after the costs have been made, this takes less time because the offer is composed parallel to the execution of the repair. The most common repaired products are repairs requested by all three customer groups, so the differences in throughput time cannot be explained by specific products.

Table 4: Mean and standard deviation (in days) of different phases in the repair service per customer group based on data and assumptions.

	Customer group	**RMA assessment phase**	**RfQ phase**	**Order acceptance + repair phase**
Mean of throughput time (days) repair service	Master	42	99	78
	Investor	45	338	234
	Executor	63	99	261
Standard deviation of throughput time (days) repair service	Master	64	43	97
	Investor	49	290	117
	Executor	70	43	153

2.4.4 Differentiation

Based on the set of data, there is also differentiation possible in the total throughput times of make or buy products. Make products are products where TNNL has a share in the production of a product. Buy products are (partly) bought from a supplier. Most buy product need to be repaired at a supplier in the repair process. For make products the knowledge is present to repair it internally. Table 5 shows per customer group the ratio buy/make products and their throughput times.

Table 5: Mean of throughput time (in days) of buy or make products in the repair service per customer group.

	Master	**Investor**	**Executor**	**Total**
Mean of throughput time (days) repair service	238	358	314	270
Mean of throughput time (days) of buy products in repair service	244	346	268	260
Mean of throughput time (days) of make products in repair service	233	372	372	277
% of buy products	40%	53%	56%	42%
% of make products	60%	47%	44%	58%

Table 5 shows that make products have a longer throughput time than buy products. This is not a significant difference, it could be a statistic fluctuation. However, according to an interview with the supervisor of TNNL, there is a reason behind this. Make products are often more complex than buy products, and sometimes there are buy products needed for the repair of make products. So, the repair process at TNNL takes longer than the repair process at a supplier. This explains why the mean throughput time of make products is higher than for buy products. However, there is only a minor difference between the throughput times of repairing make or buy products when analysing all repairs. The big difference between make and buy product repairs is visible at the executor group. The mean throughput time of buy products is 28.0% lower than the mean throughput time of make products. When looking for interventions, this big difference could be a point of attention.

When looking at the percentages of Table 5, it shows that the investor and executor group have a higher percentage of buy products repaired. However, the majority of the repairs (58%) is a make product. This is because the master group is the biggest share of all repairs. In general, the percentages of the division make or buy products fluctuate around a 50/50 rate. There is no clear reason for the fluctuations, so also no conclusion for further research.

When it comes to external repairs there are a lot of suppliers that TNNL has. Suppliers play a big role, so it is important to take a look at them. Table 6 shows the top 10 most used suppliers of TNNL the past five years, their number of repairs, and their average throughput time per repair.

Table 6: Mean of throughput time (in days) and the number of repairs of the top 10 most used suppliers the past five years.

Supplier	**Number of repairs**	**Mean of throughput time (days)**
Supplier 1	77	236
Supplier 2	77	282
Supplier 3	60	205
Supplier 4	57	330
Supplier 5	43	140
Supplier 6	41	392
Supplier 7	31	441
Supplier 8	30	243
Supplier 9	29	342
Supplier 10	27	208

Table 6 shows the suppliers with a substantial number of repairs. There are a few suppliers that stand out; suppliers 4, 6, 7, and 9 have a mean throughput time higher than 300 days. In Chapter 4, when looking at the interventions, it could be possible to select the repairs from these suppliers to avoid these high throughput times. Interesting to see is that suppliers 3, 4, 6, and 7 only supply to master customers, while the other suppliers supply to all customer groups. It can be concluded that the customer group does not influence the throughput times of suppliers, since suppliers with mean throughput times higher than 300 days do supply to all customer groups. There is no straight correlation between a supplier and throughput time.

TNNL repairs with a lot of suppliers, and they repair a lot of different products. These products are specified with for each their own item code. Table 7 shows the top 10 most repaired products the past five years, their number of repairs, and their average throughput time per repair.

Table 7: Mean of throughput time (in days) and the number of repairs of the top 10 most repaired products (items) the past five years.

Item code	Number of repairs	Mean of throughput time (days)
Item A	125	178
Item B	56	209
Item C	51	317
Item D	41	392
Item E	40	316
Item F	32	414
Item G	31	441
Item H	30	178
Item I	28	272
Item J	27	144

Table 7 shows the products with a substantial number of repairs. There are a few products that stand out; item C, D, E, F, and G have a mean throughput time higher than 300 days. In Chapter 4, when looking at the interventions, it might become interesting to intervene these repairs. The items with a mean throughput time higher than 300 days include both make and buy products. And a conclusion about whether a supplier influences these outliers cannot be made either.

Just like Table 6, Table 7 is based on the top 10 most common repairs. With the knowledge that 72.5% of the repairs is requested by the master group, it is no surprise that the majority of the top 10 items and suppliers is involved in repairs for the master group. Therefore, this analysis cannot give a conclusion about the influence of customer groups on the length of throughput times.

2.5 Conclusion

In this chapter, the question "How can I give an overview of the current situation of the end-to-end process flow?" is answered by means of interviews, a business process model, a root cause analysis, and a literature study.

The repair service can be divided in four different phases, starting with the RMA assessment phase. In this phase, the customer contacts the customer contact centre (CCC) to report a defect and applies for an RMA. The CCC is responsible for the communication and information flow between the customer and TNNL. The next phase starts when TNNL receives the repair part with an RMA code, this is the return for quotation phase. Here, the repair shop inspects the repair part and cooperates with the CCC to determine the price and lead time of the repair. The third phase is the time that TNNL waits on the approval of the offer. When the offer gets accepted, the actual repair starts, in other words the last phase. In this phase, the procurement department gets involved in the process to take care of the external repairs at the suppliers, meanwhile the repair shop takes care of the internal repairs. The RMA assessment is the shortest phase which takes up to two months, and the RfQ phase is the longest. The RfQ phase takes very long, from three months up to more than a year.

The root cause analysis showed various root causes of the low customer satisfaction. With this analysis, it became clear that the potential of improvement is within the organisation of the repair service. Important root causes are the fact that the current repair service is a reactive instead of a proactive service, decisions are not made on the right level of organization, and there is lack of criteria on repairs entering the repair process. This results in the high throughput times since TNNL sees every repair order as unique case and there is no structural management within the organisation. To improve the repair process, the organisation of the repair service should be changed to decrease the throughput times.

In the data analysis of the current situation, most information could be obtained from the throughput times. To quantify improvements, which will be suggested in Chapter 4, the throughput time will be used as the customer satisfaction indicator in this research. The focus will be on the throughput time, so not on the other indicators because it is harder to quantify these. The data analysis made the biggest difference in throughput times between customer groups clear.

The analysis of the current end-to-end process flow gives a start to modelling the current repair service. This will be constructed in the next chapter. The data analysis of the current repair service showed that the throughput times of the repair service could be grouped per customer group, different supplier, and per specific product. Here, it became clear that interventions could be suggested based on the different customer groups since there is a significant difference. Repairs from the master customer group encounter the least problems with a an average throughput time of 219 days, the Investor customer group has the longest average throughput time of 627 days. There are no significant differences when analysing the different suppliers and specific products, or a combination of these groups. For example, combining differentiation between customer group and supplier. After all, the customer groups have the most impact on the throughput times of the repair service and will be of interest when looking into the intervention in Chapter 4.

3 Modelling the end-to-end process flow using data

In this chapter, the current end-to-end process flow is modelled. I will identify a simulation method to model the current end-to-end process flow. After identifying the simulation method, I will analyse the available data to link distributions to the different phases in the repair service. Based on this analysis, I will make some assumptions, so I can reconstruct the repair service by means of simulated repair orders. After validating the model, this model is the start of introducing interventions. I chose to simulate because implementing interventions using calculations is rather complex when suggestion interventions on a specific group of repair orders. Before proposing and choosing interventions, I will build a simulation of the current situation. With this model, I can easily implement different interventions and see what impact they have. When simulating, an insight of the distribution is provided. Questions like, where are the peaks in the distribution, and what is the behaviour of the distribution, could be answered. This gives the opportunity to see the chances of a certain outcome. This is helpful when the input is changed a lot.

3.1 Simulation method

The goal of a simulation is to create an imitation of a system (Robinson, 2014). In this research, an imitation of the repair service is created by means of the simulation of throughput times of repair orders. When the simulation creates a representative set of repair orders, the behaviour of the current repair service can be analysed. This is an insight in the distribution of throughput times. This is the first step to analyse interventions within the repair service. When simulating interventions, it is of interest what the behaviour of the system does.

Partly based on the output variables of the simulation, a recommendation about the interventions should be made. These output variables are the mean, and the variance.

According to Robinson (2014), there are four primary approaches for simulation. These are discrete-event simulation, system dynamics, agent-based simulation, and Monte Carlo simulation.

- Discrete-event simulation is based on queueing systems. Since the repair process will be simplified with unlimited capacity, this type of simulation does not fit the research.
- System dynamics represents the world as stocks and flows, where the stocks are items, people, or money and the flows adjust the level of these stocks. System dynamics focusses input and output flows, which is different from the distributions of the throughput times of repairs and therefore it does not fit the research.
- Agent based simulation has the aim to observe the behaviour of individuals that interact over time. This does not fit the repair service in this research.
- Monte Carlo simulation is used to model a certain risk in an environment with an outcome that is involved with chance.

The Monte Carlo simulation fits the repair service in this research well because the throughput times of the different phases are uncertain and subject to chance.

3.2 Distribution phases

The fixed input data of the simulation consists of the throughput times of the different phases (and possibly customer-specific throughput times per phase). To make sure the simulation runs properly, the throughput times should be generated randomly based on a distribution. To determine which distribution it follows, the input data should be analysed, the Anderson-Darling statistic is used to test the goodness-of-fit of a distribution to the fixed input data. The Anderson-Darling statistic is often used when there is not a lot of data available (Engmann & Cousineau, 2011).

Figure 7 shows the value of this statistic and the extent to which the data of the RMA assessment phase follows the different distributions. At first sight, an empirical distribution was excluded, since other distribution could match with the data. This is tested against four of the most common distributions; these are the normal, lognormal, exponential, and gamma distribution. Since the lognormal and the exponential distribution cannot work with zero-values, these values have been changed to 1 in the dataset. Because of this, a lot of values in the dataset have a value of one, which explains the vertical line in the probability plots. And this opens the next question why there are this much low values. The RMA assessment phase starts when the customer contact TNNL about a defect and the phase ends when TNNL receives the defect part. Can these low values be explained, or could these be errors in the data? This question cannot be answered since there are arguments that could explain why there are so many low values, and there are arguments that could tell otherwise. It could be the case that there are repairs with high urgency that are delivered in one day, or it could be that the repair is created when the defect part is already at TNNL. To make sure that no correct data gets deleted, these low values are used in the identification of the distribution.

From the analysis in Figure 7, it can be concluded that the data fits the best according to the gamma distribution, since it has the lowest AD value, and it follows the red line the best. Because there are no significant differences in the RMA assessment phase per customer group (see Table 4), the distribution is based on data of all repair orders.

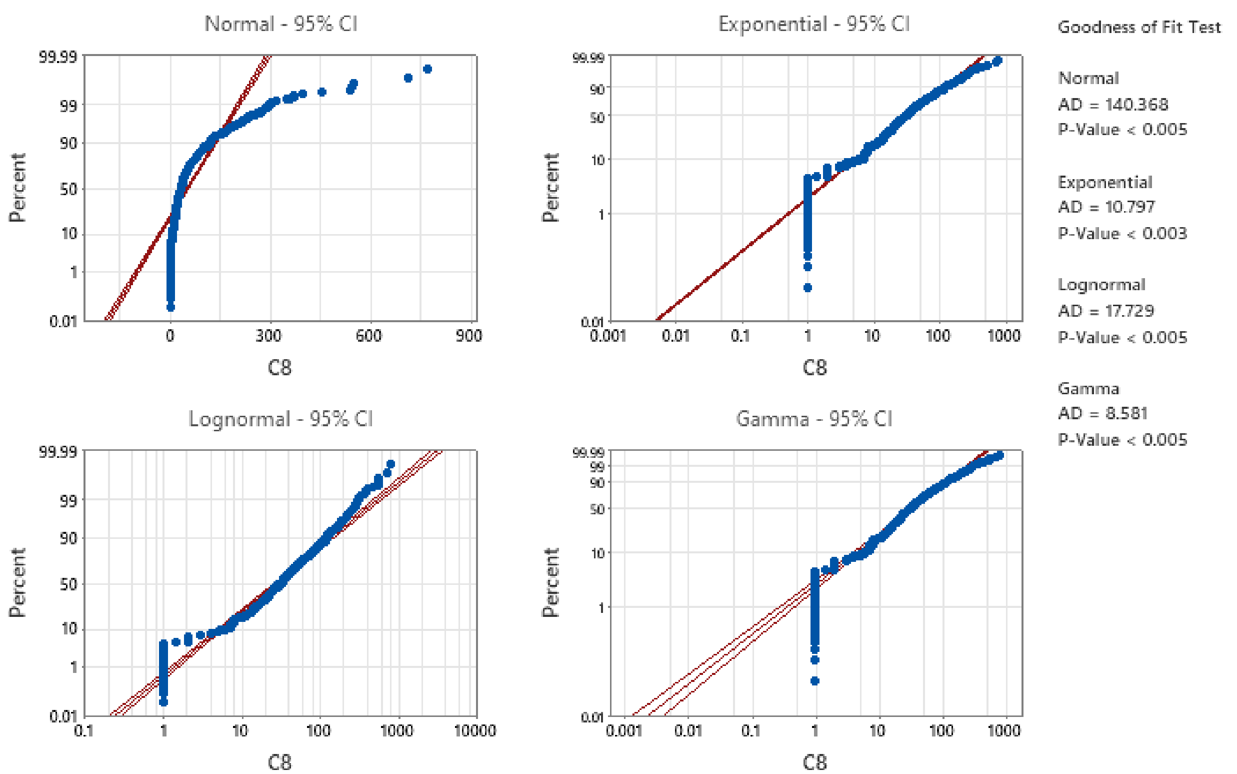

Figure 7: Goodness-of-fit test on the throughput times of the RMA assessment phase

For the RfQ phase there are customer-specific datasets. This is because the behaviour of the different customer groups influences this phase a lot. In appendix F these datasets are plotted against the four most relevant distributions resulting in the simulation distributions in Table 5.

There is no data present for the executor group in the RfQ phase, therefore I spoke with an employee who is responsible for this customer group. The expert opinion gave a random distribution between the 60 and

120 days. However, the repair process runs most smoothly for the master group, so a mean of 90 days for the executor group is not realistic. It should be at least 99 days according to the data of the master group (see Table 4). And that is why I assumed the distribution of the executor group to be equal to the distribution of the master group (gamma distribution).

For the order acceptance and repair phase, there are also customer-specific datasets. In appendix G these datasets are also plotted against the four most relevant distributions resulting in the simulation distributions in Table 8.

Table 8: Distribution per phase per customer group.

Customer group	**Distribution RMA assessment phase**	**Distribution RfQ phase**	**Distribution repair phase**
Master	Gamma distribution	Gamma distribution	Lognormal distribution
Investor	Gamma distribution	Lognormal distribution	Lognormal distribution
Executor	Gamma distribution	Gamma distribution	Normal distribution

3.3 Assumptions

Throughout the simulation a lot of assumptions have been made. This is because this is for the benefit of the simulation. The assumptions are explained down below:

As already explained, the capacity at every phase is infinite. This way the model can be simplified, and we avoid creating a queueing model. The throughput times include waiting time which covers the capacity (and therefore queuing) in a way.

Within the repair process, there are repairs under warranty and repairs including a contract between the customer and TNNL. These repairs are excluded from this analysis since these repairs do not need a request for quotation and order acceptance. These phases are skipped because the TNNL does not need to compose an offer and the customer does not need to accept an offer. These repairs follow a shorter route within the repair service and to simplify the analysis these are not considered in the analysis.

TNNL executes repairs internal and external at the supplier. The separate repairs have different throughput time distributions, but these are not simulated individually. They are simulated combined since the interventions do not influence internal or external repair throughput times.

3.4 Simulation model

In order to create a relevant simulation, I simulated 2251 repair orders, just like the amount of available repair orders in the database of TNNL. Law & McComas (1991) recommend, as a rule of thumb, to make at least three to five independent runs. In this simulation five repetitions are made, to obtain a accurate mean and standard deviation.

Based on the data obtained from the enterprise resource planning system, the following distribution of the throughput times of the complete repair service appeared (see Figure 8). This distribution has an average of 270 days with a standard deviation of 201 days.

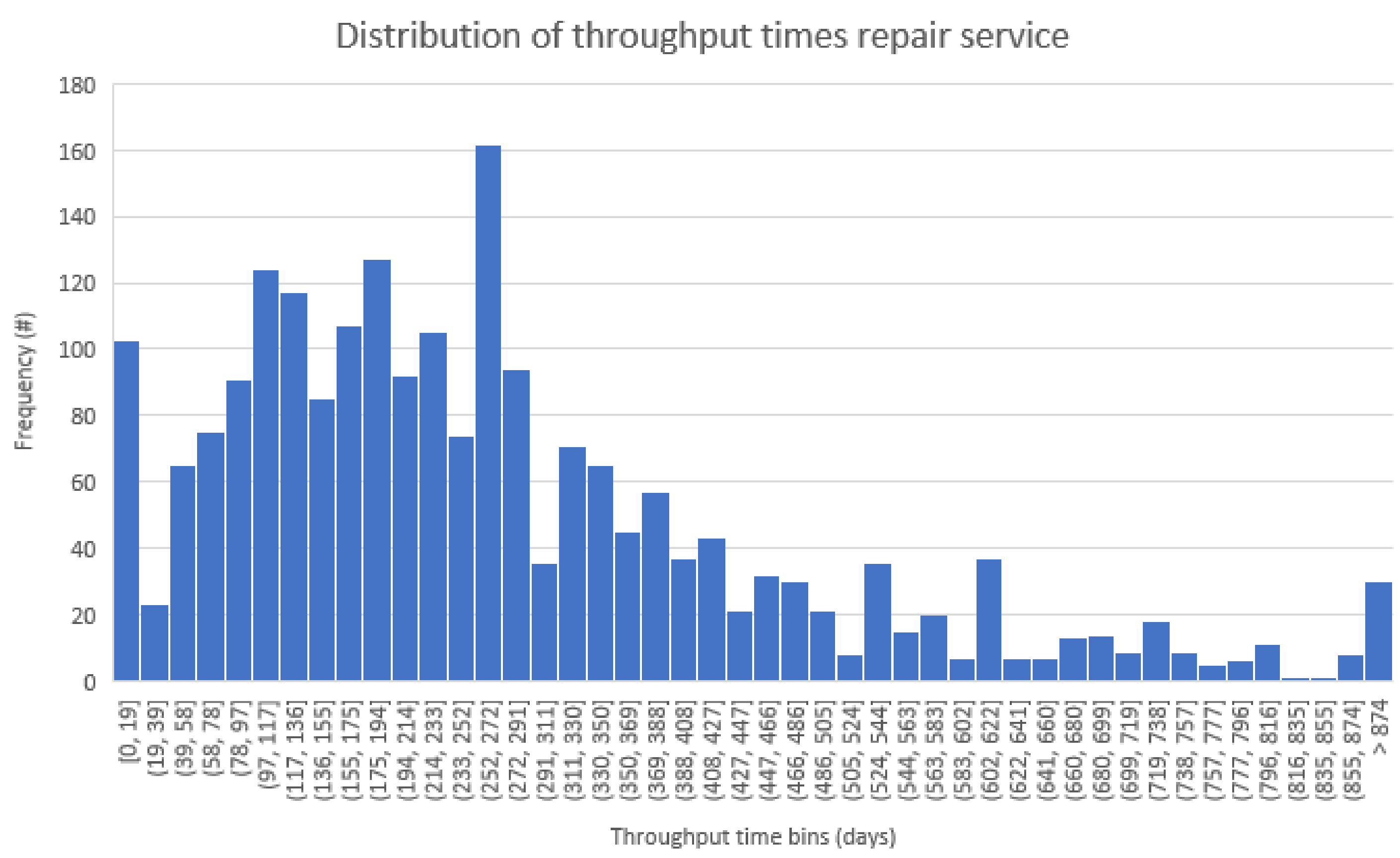

Figure 8: Distribution of throughput times of the repair service based on historical data.

With help of the time stamps within the repair process, I created my own Monte Carlo simulation (shown in Figure 9). The input variables are the ratio between the different customer groups which is 72.5% master group, 2.0% investor group, 20.4% executor group, and 5.1% attendant group. The attendant group is excluded so this results in 76.4% master group, 2.1% investor group, and 21.5% executor group. In the simulation every repair order corresponds to a customer group based on these percentages.

The total simulated throughput time is built up from the three phases following the distributions of the corresponding customer groups (excluding the attendant group). When simulating 2251 repair orders the distribution in Figure 9 is created. The simulated distribution gives an output of an average throughput time of 277 days with a standard deviation of 167 days. This differs somewhat from the data (see Figure 8), however this difference originates from the assumptions being made. Besides, it could be the case that the attendant customer group is responsible for this difference. In the end, the conclusions are drawn based on the influence of interventions on the distribution of the simulated current simulation.

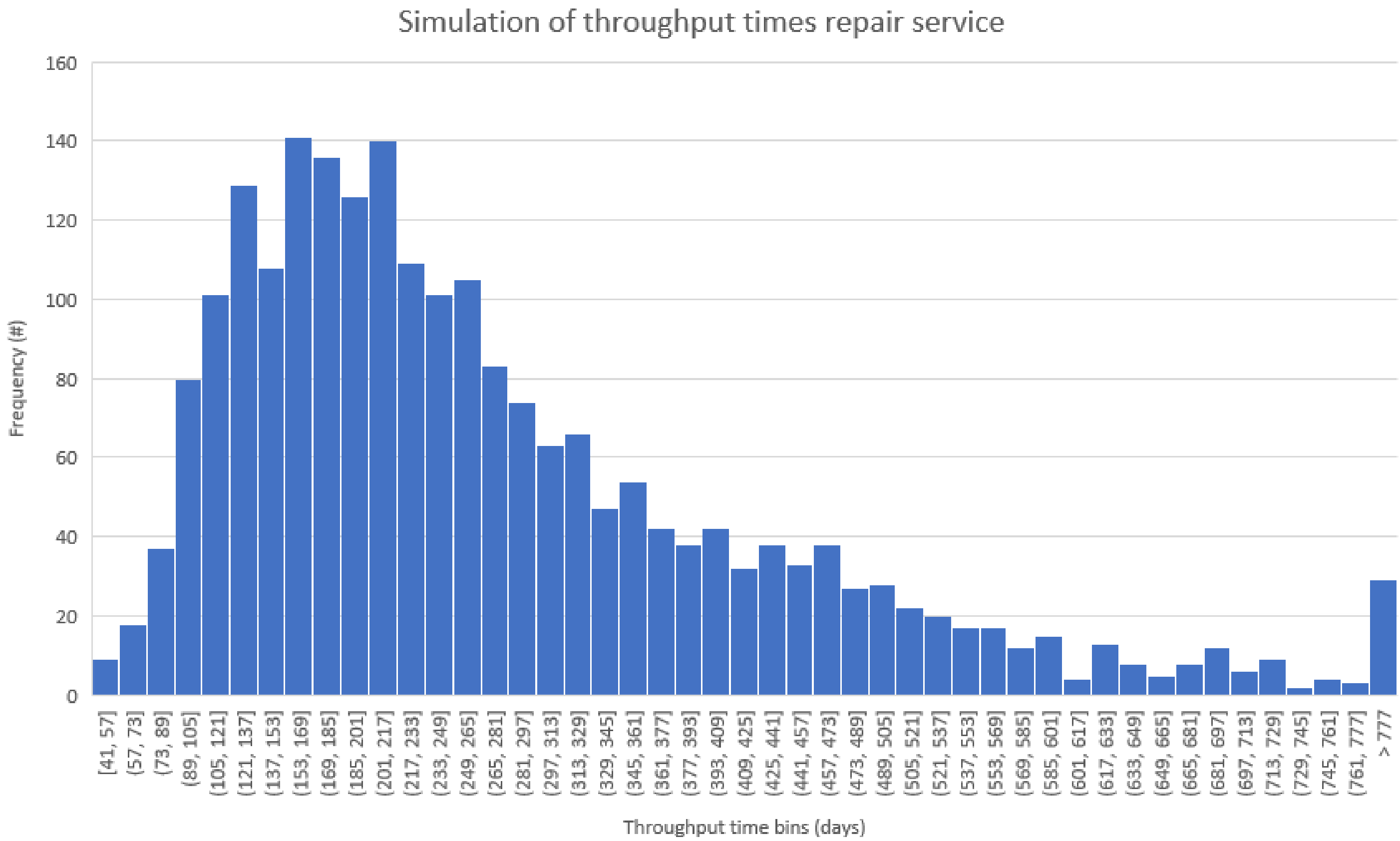

Figure 9: Simulated distribution of throughput times of the repair service

3.5 Validation and verification

Validation and verification of the model has to do with the representation of real life. Is the model used actually a representative model? For simulation there are a few methods available for validation and verification.

Data validation

One of the validation methods is data validation. At every cost, it should be ensured that the data is as accurate as possible. A modeller should investigate the sources of the used data in order to determine the reliability of the data (Robinson, 2014). In this research, data has been used from the ERP system. In collaboration with the employees responsible for this data, it has been used. Minor mistakes in the notation of the data could be possible, however due to the large number of data, these are negligible. Also, some assumptions have been made in consultation with experts, so the used data can been seen as valid.

White-box validation and verification

Another method is white-box validation and verification. Robinson (2014) states that although white-box validation and verification are conceptually different, they are combined because they are both performed continuously throughout model coding. Two examples of white-box validation and verification are checking the code and visual checks.

A modeler needs to check his or her code throughout model coding to make sure that the right data and logic is used at the right place. Robinson (2014) suggests explaining the code to someone else as second check. With the help of the supervisors of TNNL, this worked out. Besides this the simulation is built up from throughput times of the different phases. These phases work as an intermediate step to check if the outcome is logic.

With the automatically generated histogram of total throughput times, a visual check is created. The behaviour of the simulation can be checked and when entering extreme input values, it can been checked if the model behaves as expected.

Black-box validation and verification
In black-box validation and verification, the real system is compared to the simulation model (Robinson, 2014). With this given, the following aspects are compared: the throughput times of the total repair service and the RMA assessment phase.

Table 9: Comparison real data and simulated data.

Phase	Distribution	Mean of data	Simulated mean	Difference	Standard deviation of data	Simulated standard deviation	Difference
Total repair service (days)	Built up from different distributions	269.970	276.481	6.511 (2.4%)	201.291	166.688	34.603 (17.2%)
RMA assessment (days)	Gamma	51.006	50.825	0.819 (1.6%)	64.61629	62.81687	1.79942 (2.8%)

When comparing the average and standard deviation of the data to the simulated mean and standard deviation, there is quite a big difference between the accuracy of the total repair service throughput time, and the RMA assessment throughput time. The reason behind this is that the total repair service simulation is built up from different simulated phases, with each their own conditions and assumptions. The simulated mean of the total repair service differs 2.4% from the data, which indicates that the throughput times generated by the simulation are sufficient according the standard error of the mean (5.9%). The simulated standard deviation differs 17.2% from the data, which is too much (standard error is 3.5%). However, this can be explained since multiple distributions with assumptions are add up together with each their own standard deviation. An additional reason for the difference between expectation and simulation is that the phases are simulated with data from one representative customer per customer group. This representative customer might differ a bit in behaviour of the whole customer group. The reason why the data of one representative customer per customer group is chosen, is because of the lack of data of other customers within the customer groups.

The goal of the simulation is to get an insight in the behaviour of the repair service. Based on the data validation, white-box, and black-box validation and verification, it can be concluded that the simulation model is valid.

3.6 Conclusion

In this chapter, a Monte Carlo simulation of the repair service has been built up from different aspects. The process has been simplified to the three phases RMA assessment, RfQ, and order acceptance + repair. Each phase has their own distribution based on the customer groups. Data of the repair service has been analysed to identify the top 10 suppliers and products. These can be used in the intervention of the next chapter. The simulated distribution gives an output of an average throughput time of 277 days with a standard deviation of 167 days. This differs somewhat from the historical data (see Table 9), however this difference originates from the assumptions being made. Despite this fact, the model has been proved valid, so this will not influence the conclusions and recommendations.

4 Formulating methods for improvement

After the current situation is simulated, the concept interventions can be implemented in the simulation to quantitatively analyse them to see if it would improve the repair service. The implementation of the interventions in the simulation is very easy. In the end of this chapter, a conclusion can be made based on this implementation. This chapter elaborates on suitable interventions. All options are plotted, explained, and the impact on the repair service is elaborated. These solutions originate from discussions within the meetings with important roles of the repair service, where I tried to bring up possible solutions where the interviewee could bring up new or existing ideas.

Currently, TNNL repairs all their products if customers have any problems with them. It can be stated that every repair order is completely customisable since every repair needs other actions. The situation right now is that when a repair order enters TNNL, every custom action has to be executed. There are no standardised actions within the repair process. This situation results in a lot of individual attention for each repair, but it also causes delay. For example, when a customer agrees on the proposed offer, after that, the components will be ordered for the repair. Before the execution of the repair, waiting time for the components should be included.

This situation is best explained with the theory of the customer order decoupling point (CODP). CODP is the way in which customer orders influence the operations of a process (Gosling et al., 2017). It is the point that is a buffer between the fluctuating customer orders and the smooth output of an organization. This point varies between high variety, low volume and low variety and high volume. Slack et al. (2019) define three types of service processes. These are professional services, service shops, and mass services. Professional services provide high levels of customization, it is highly adaptable to the customer needs. Meanwhile, mass services have many customer transactions, like a supermarket. Service shops are the range of service types, with a medium level of variety and a medium level of volume.

The repair service at TNNL can be identified as a process with a customization of every service. It can be defined as professional service. Every repair part will be examined to look for its specific repair. An improvement for the repair service would be to shift the CODP. This way the flexibility and the low volume and high variety could be more balanced. With a more standardised process, the process variability decreases, and this allows a higher process utilization without longer waiting times, as Figure 10 shows (Slack et al., 2019).

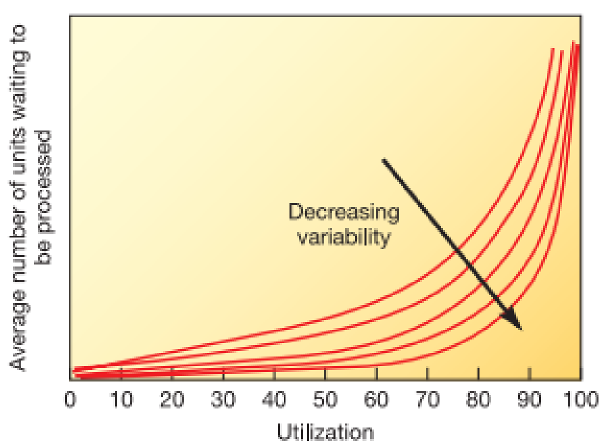

Figure 10: The relationship between process utilization and number of items waiting to be processed (Slack et al., 2019).

4.1 Loan-item

In the current repair process, the customer could be non-operational for a long time because the customer has to wait for the repair. The repair process takes long, there is a lot of unclarity, and there is little communication.

This improvement contains a loan-item. For the most common repair parts, a loan-item will be kept on stock. This loan-item will replace the part to repair meanwhile the repair part gets repaired, this is also called a line replaceable unit. In these cases, customers will be operational when the RMA application is accepted because a loan-item will be returned to the customer. This process is shown in Figure 11, where Z is the percentage of repairs where a loan-item is present.

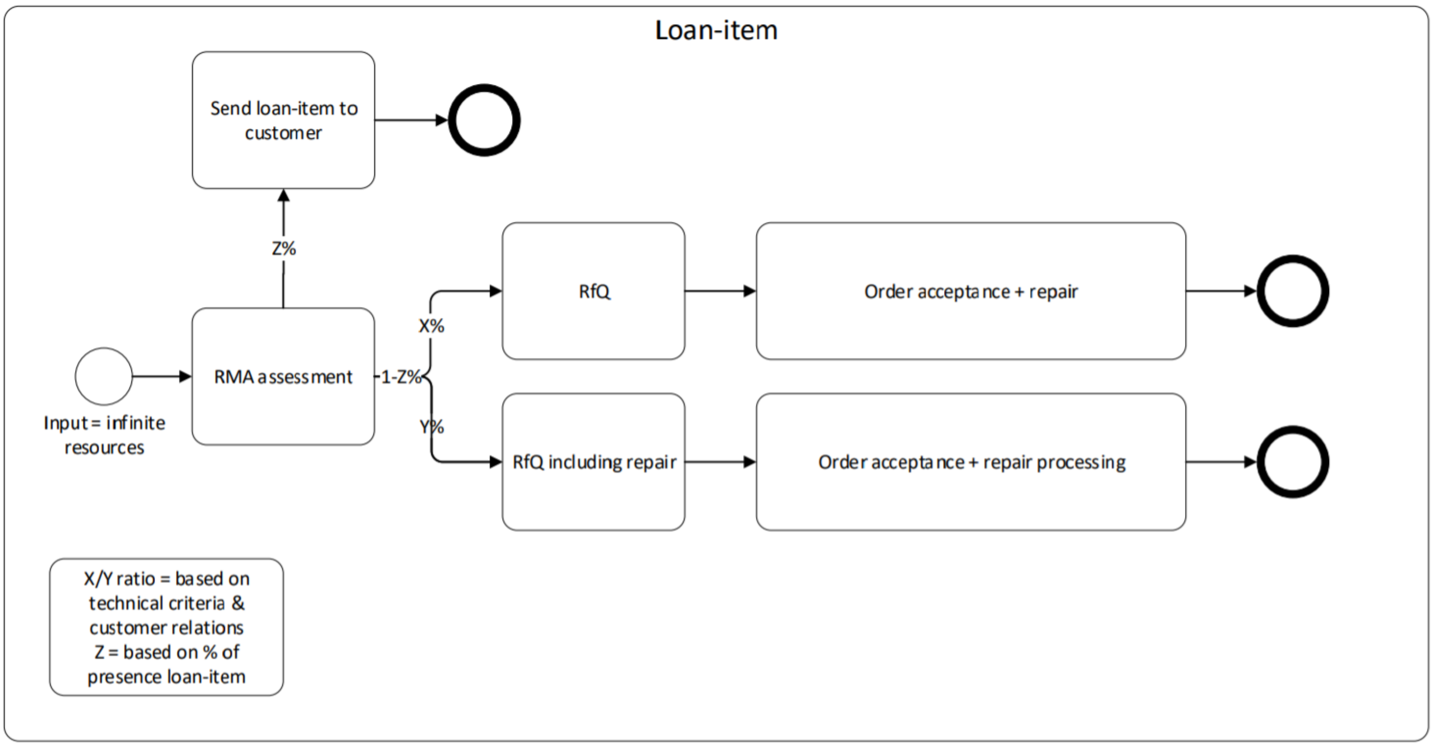

Figure 11: The process model of the repair process including a loan-item based on the present time stamps.

The improvement is implemented in the simulation by an extra input variable, which is the percentage of a repair where a loan-item is used. The time the customer is non-operational will change from the throughput time of the whole repair process to the time until the receipt of the loan-item if this is present. This is the time that TNNL takes to send a spare part to a customer, which has a standard throughput time of 60 days. In the distribution of the throughput times of the repair service this results in a peak in the low throughput times (see bin 55:69 in Figure 12) after which it continues with the original distribution.

Nine out of ten of these items are obsolete and are a representation of items that will be repaired in the future. Exact amounts of inventory are therefore unknown. As representation of the future, the items C, D, E, F, and G can be considered to keep on stock. These are within the top 10 most repaired items, and those have a really long throughput time (higher than 300 days on average), so it would be very beneficial and effective to implement a loan-item for these products. This means for 9.0% of the repairs, there is a loan-item present. Z (see Figure 11) is 9.0%.

Besides the benefit in throughput time, there are also costs involved with a loan-item. The total intervention price of a repair with loan-item consist out of the original repair price, the inventory costs, and depreciation costs.

Based on an expert opinion, the original repair prices vary between the 3,000 and 10,000 euros. The most common repairs are used in this assumption, because the current top 10 repaired items are mostly obsolete and therefore not relevant for an intervention in the future. The question is if this intervention should be implemented for future repairs.

The inventory costs are the costs to keep the loan-item on stock when it is not lent out. TNNL charges 25% of the cost price of the loan-item for this per repair. These inventory costs are based on the same inventory cost percentage of spares track. This is a similar service process at TNNL and the inventory cost percentage is therefore assumed to be the same in the repair track. This 25% is a one-time payment included in the total repair price. It covers the average inventory costs of items on stock and also the costs for the increase of value of the repair because of a faster throughput time.

Next to the inventory costs, there are depreciation costs. Loan-items are in possession of TNNL, so the cost price of the loan-items should be paid back. Ultimately, the customer can execute their activities longer. According to an expert opinion, the items in the top 10 most repaired items could be lent out 5 times. A normal repair could in the extreme case take up to 3 years to be finished and some systems can operate 15 years. To take the extreme case as starting point, a loan-item could be lend out 5 times. This means that the depreciation costs are 100/5=20% of the cost price. In total, the extra costs for repairing with a loan-item are 25+20=45***%*** of the cost price.

If the repair costs exceed 60% of the cost price, the repair is not worth the costs. The advice from TNNL to the customer is to buy a new product.

The costs of the top 10 most repaired items vary between 25,000 and 50,000 euros. Because 9 out of the 10 items are not produced anymore, this assumption has been made based on an expert opinion. The original repair price should be below 15% of the cost price (to prevent exceeding 60% of the cost price). In case of an item that costs 25,000 euros, these costs are 3,750 euros. In case of an item that costs 50,000 euros, the original repair price should not exceed 7,500 euros.

Since the original repair prices vary between the 3,000 and 10,000 euros, a lot of repairs (most original repairs worth more than 3,750 euros) a loan-item is not worth it, since the advice of TNNL is to buy a new product.

When involving all different repairs, the new repair price would be between 14,250 and 32,500 euros.

Table 10: Repair price of a loan-item intervention

Intervention	**Repair costs**	**Inventory costs**	**Depreciation costs**	**Total repair price**
Loan-item	3,000-10,000 euros	6,250-12,500 euros	5,000-10,000 euros	14,250-32,500 euros

Figure 12 shows the distribution of throughput times with a loan-item resulting in the output variables, which are the average throughput time of 240 days and a standard deviation of 162 days. It shows the effect of the intervention 'loan-item', the number of repairs with a loan-item is to be discussed.

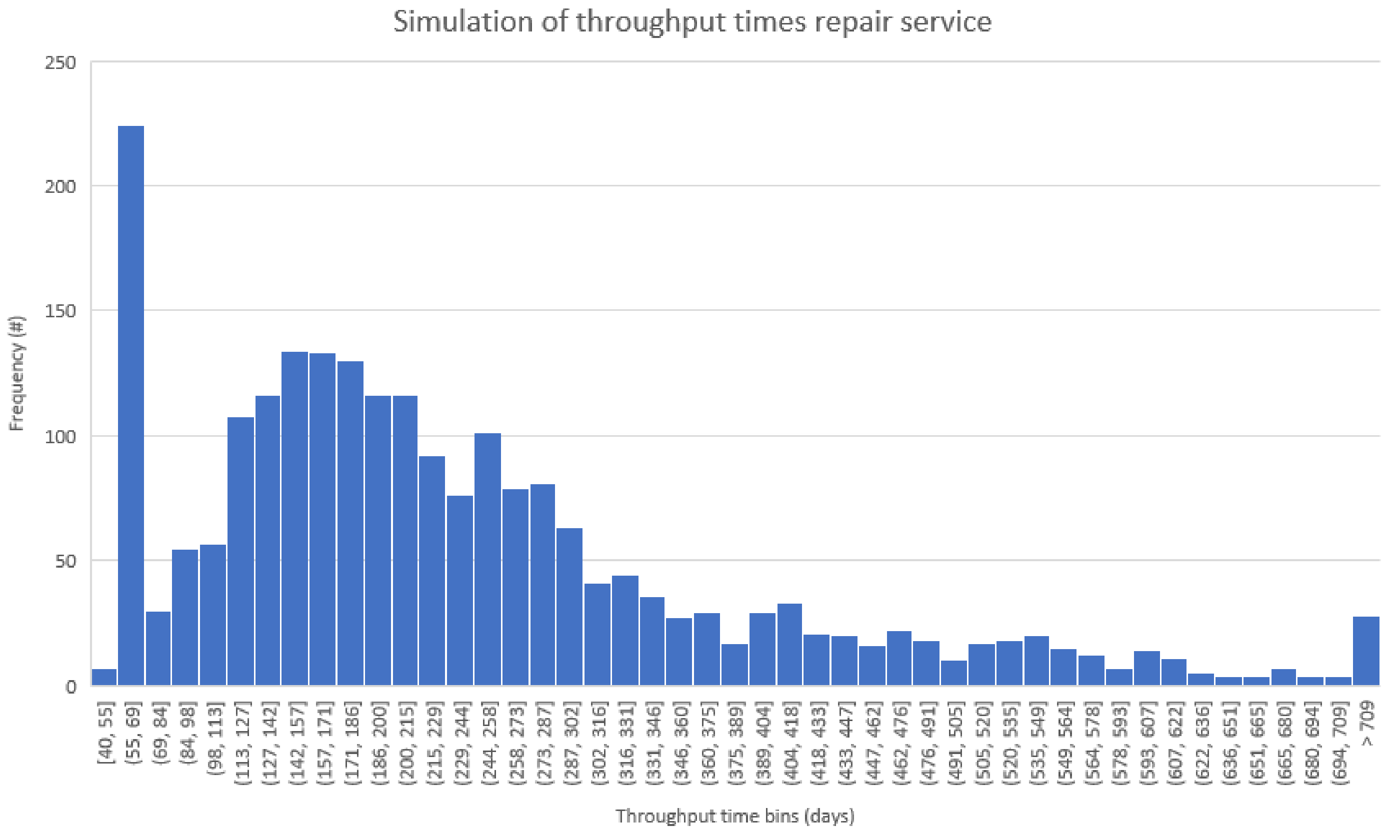

Figure 12: Simulated distribution of throughput times of the repair service with a loan-item.

4.2 Inventory

The current repair process has a high variety of throughput times. This is because the repair service relies on a lot of third parties, the suppliers. When a repair offer gets accepted, TNNL has to order all required components for the repair.

An option to shift the CODP is to keep stock of frequently used components that are needed for a repair. This is about parts within the product that need to be replaced, the shop replaceable units. Currently, in exceptional cases there are components on stock. However, there is no structural inventory management, there are no shop replaceable units in the 30-year-old products that TNNL repairs right now. A structural inventory management means a shift of the CODP. It means less variety in throughput times when the suppliers do not have to be contacted anymore, because a repair is less dependent on third parties. This shift in variety of throughput times will be visible in the results of the simulation as the standard deviation, also the mean throughput time will decrease. With the implementation of inventory management, there will be no need to order all required components for the repair. This process is shown in Figure 13, where Z% of the repairs has inventory. The X/Y ratio is still the ratio between repairs with RfQ excluding/including repair. Downsides of this option are the warehouse costs and the possibility that the components, that are ordered, are left over when the prediction does not meet the reality.

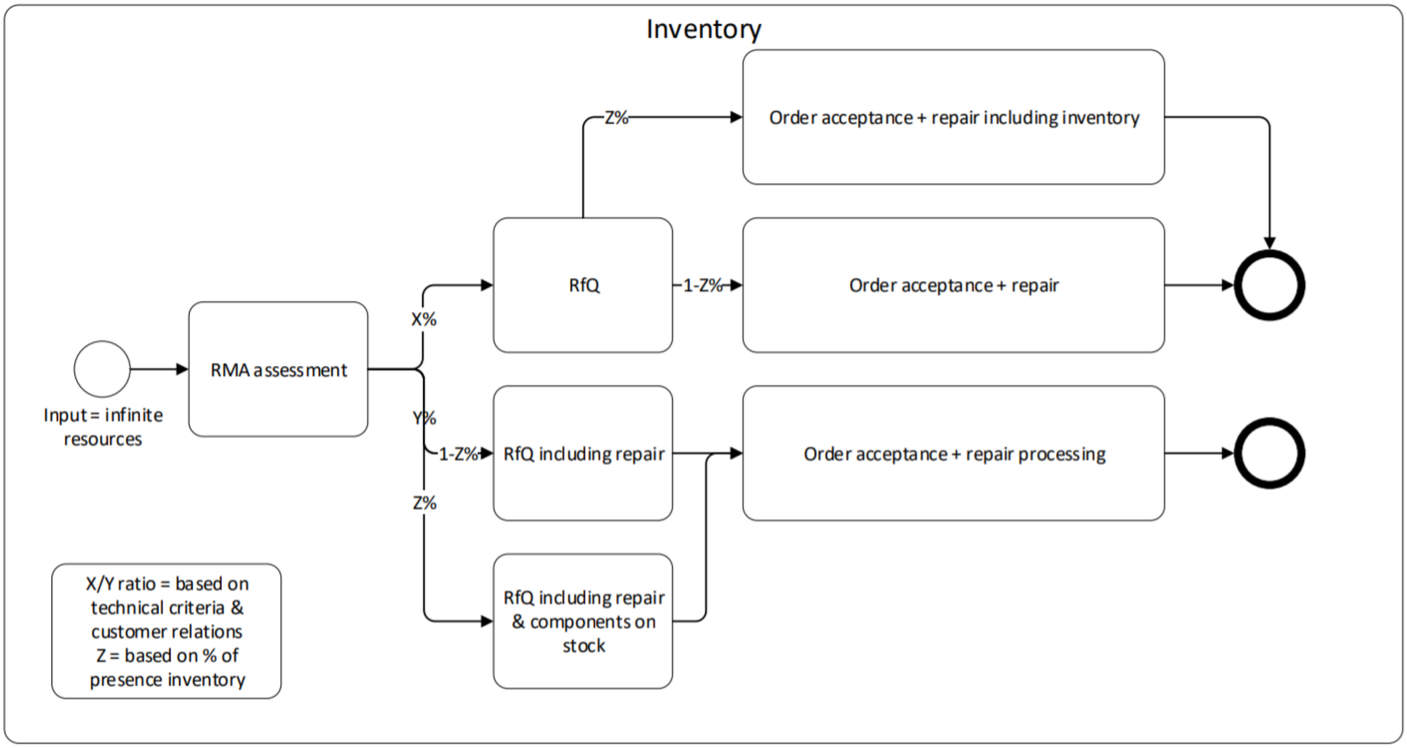

Figure 13: The process model of the repair process including inventory based on the present time stamps.

The inventory is implemented in the simulation by the percentage of a repair where inventory is used. The time the repair phase takes, decreases when using inventory (assumed to be 25% in consultation with the supervisors of TNNL). This is the time of the RfQ phase including the repair, or the repair phase. In the distribution of the throughput times of the repair service this results in a lower throughput time bin as the peak of the distribution.

Nine out of ten of these items are obsolete and do not have built in shop replaceable units. The items are a representation of items that will be repaired in the future. Exact amounts of inventory are therefore unknown. As representation of the future, components of the items C, D, E, F, and G can be considered to keep on stock. These are within the top 10 most repaired items, and those have a really long throughput time (higher than 300 days), so it would be very beneficial and effective to keep components of these items on stock. This means for 9.0% of the repairs, there is inventory present. Z (see Figure 11) is 9.0%.

For the intervention inventory, there are also additional costs. This intervention ensures that TNNL keeps components on stock. The total intervention price of a repair with loan-item consist out of the original repair price and the inventory costs of the components on stock.

Based on an expert opinion, the original repair prices vary between the 3,000 and 10,000 euros. The most common repairs are used in this assumption, because the current top 10 repaired items are mostly obsolete and therefore not relevant for an intervention in the future. The question is if this intervention should be implemented for future repairs.

The cost price of the components could vary and are included in the original repair price. According to an expert opinion of an employee of TNNL, the costs for such a component are a maximum of 20% of the cost price of an item. This means that an item of 25,000 euros has components with a maximum worth of 5,000 euros, and an item of 50,000 euros has components with a maximum worth of 10,000 euros. The additional costs consist of the inventory costs of the components. TNNL charges 25% of the cost price of the components for the inventory per repair. In total, the extra costs for repairing with inventory are 25% of the cost price of the components, just like the inventory costs at the loan-item intervention. This 25% is a one-time payment included in the total repair price. . It covers the average inventory costs of items on stock and also the costs for the increase of value of the repair because of a faster throughput time.

The maximum costs of the components of the top 10 most repaired item vary between 5,000 and 10,000 euros. In case of a component that costs 5,000 euros, the inventory costs are 1,250 euros. The costs of a repair are between 3,000 and 10,000 + 1,250 = between 4,250 and 11,250 euros. This repair price is between 17% and 45% of the cost price of an item, which is always below 60% of the cost price. The maximum costs are used in the calculation to make a worst case estimate. If this intervention turns out to be worth the costs, it will never be worse than expected.

In case of a component that costs 10,000 euros, the inventory costs are 2,500 euros. The costs of a repair are between 3,000 and 10,000 + 2,500 = between 5,500 and 12,500 euros. This repair price is between 11% and 25% of the cost price of an item, which is always below 60% of the cost price.

If the repair costs exceed 60% of the cost price of an item, the repair is not worth the costs. The advice from TNNL to the customer is to buy a new product. This is fortunately never the case when using the intervention inventory.

Table 11: Repair price of an inventory intervention

Intervention	**Repair costs**	**Inventory costs**	**Depreciation costs**	**Total repair price**
Inventory	3,000-10,000 euros	1,250-2,500 euros	-	4,250-12,500 euros

Figure 14 shows the distribution of throughput times with inventory with inventory available for 9.0% of the repairs and an inventory efficiency of 25%. This means that when there is inventory (9.0% per cent of the repairs), the repair takes 25% less time. Here, two extra input variables are used. Eventually, this results in an average of 271 days and a standard deviation of 157 days (output variables).

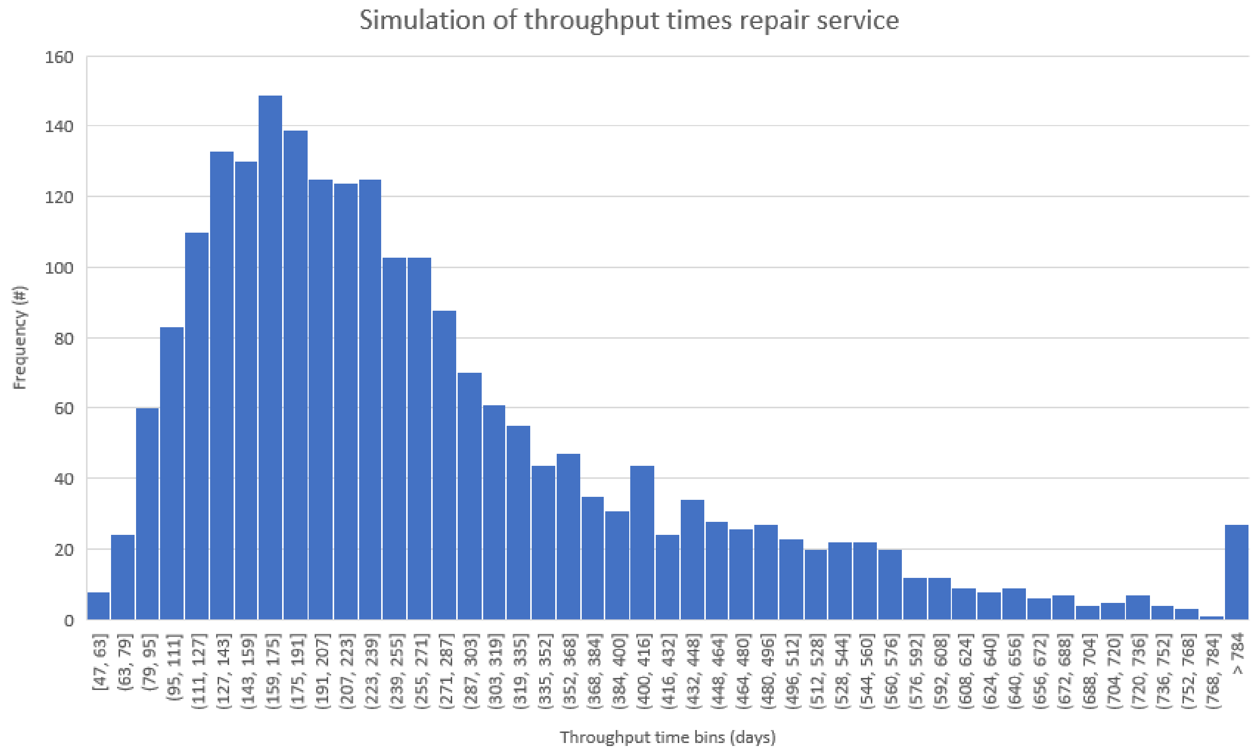

Figure 14: Simulated distribution of throughput times of the repair service with inventory.

4.3 Fixed price

A third option could be to standardise the repair service, make it less variable. The current repair process has a long phase of request for quotation, with sometimes a duration of a year. This is because the repair service relies on a lot of third parties, and every repair is different. In some cases, the defect is unknown, therefore the throughput time of this phase is long.

Currently, decisions in the process are based on an extensive RMA assessment and physical inspection. In some cases, these decisions can already be made based on previous repairs. This could be to standardise costs for a repair as a percentage of the price for a new part, in order to skip the whole cost calculation for the repair, a fixed price. An additional advantage of a fixed price is that it filters out the repair orders where the customer denies the offer when the process is halfway. Figure 15 shows the phases the repair process follows.

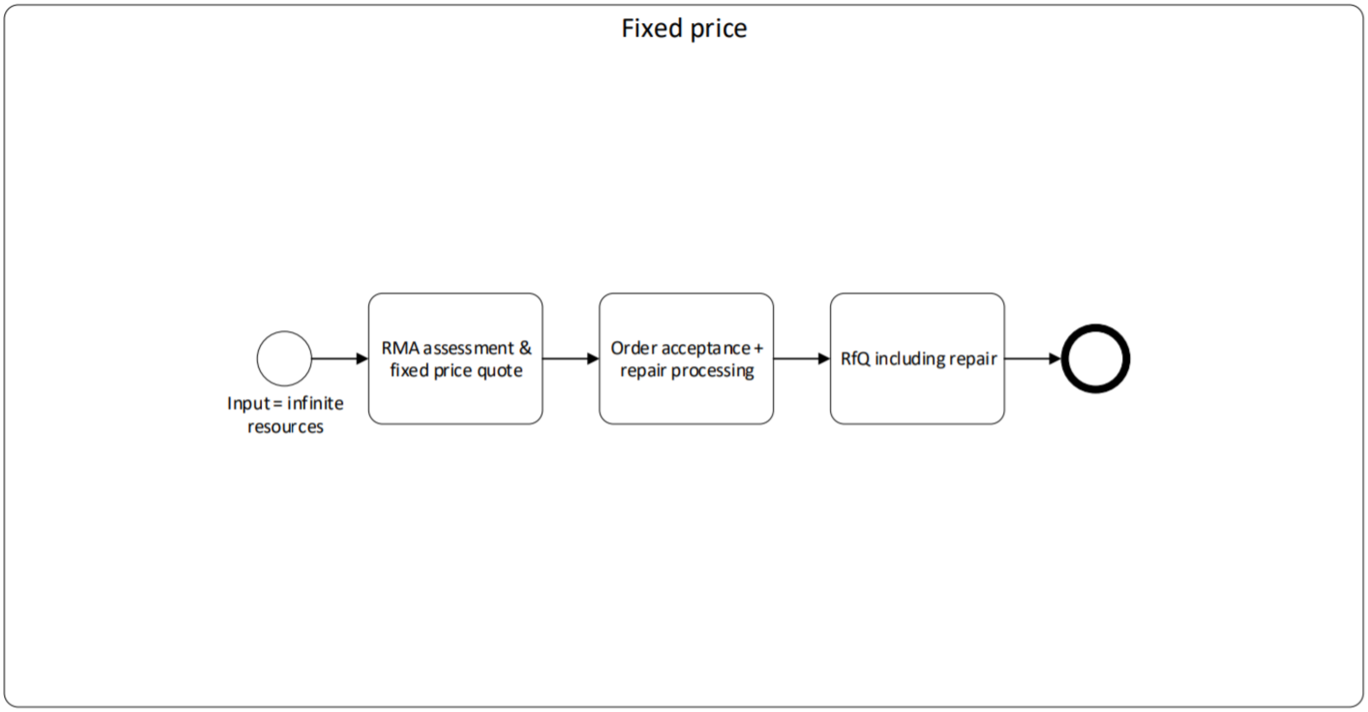

Figure 15: The process model of the repair process including fixed price based on the present time stamps.

The extra input variable 'fixed price' is implemented in the simulation by only using the RfQ phase including the repair. The RfQ phase disappears partly and is combined with the actual repair. In the distribution of the throughput times of the repair service this results in a lower throughput time bin as the peak of the distribution.

The most beneficial way to implement the fixed price, would be on the most common repaired items with the highest throughput times. These most common repaired items are the items C, D, E, F, and G. These are within the top 10 most repaired items, and those have a really long throughput time (higher than 300 days), so it would be very beneficial and effective to use a fixed price. This means for 9.0% of the repairs, there is a fixed price. Customers could prefer the current way of working in some cases, so that is why not all repairs use fixed price.

For the intervention fixed price, there are no clear extra costs. Some man-hour costs will disappear, some commercial costs will appear. More important are the risks that TNNL takes when integrating fixed price in the repair service. There is a risk where the incurred costs could exceed the paid fixed price due to cost fluctuations or obsolescence of components. When a component becomes obsolete, it is not available anymore at the supplier. Then, TNNL should search a new supplier (probably more expensive) or TNNL should redesign the component. This increases the costs of the repair. The goal of TNNL should be to prevent exceeding the fixed price. Based on an interview, the current repair costs vary between 3,000 and 10,000 euros. Due to the high variation of the repair price, this would mean that a fixed price should be close to 10,000 euros to minimize the chance of exceeding the fixed price.

If a fixed price is used, there are overhaul costs included of 1,500 euros. So, this will increase the repair price. On the other hand, some costs disappear in the RfQ process, so eventually the repair price will not differ much.

There is a case and a chance where TNNL has more costs than the fixed price. This is when the customer has agreed on the fixed price and eventually TNNL finds out that a product cannot be repaired. TNNL should buy a new product for replacement to comply to the fixed price contract.

Table 12: Repair price of a fixed price intervention

Intervention	**Repair costs**	**Inventory costs**	**Depreciation costs**	**Total repair price**
Fixed price	3,000-10,000 euros	-	-	10,000 euros

Figure 16 shows the distribution of throughput times with a fixed price for 9.0% of the repairs. Eventually, this results in the output variables which are an average throughput time of 264 days and a standard deviation of 161 days.

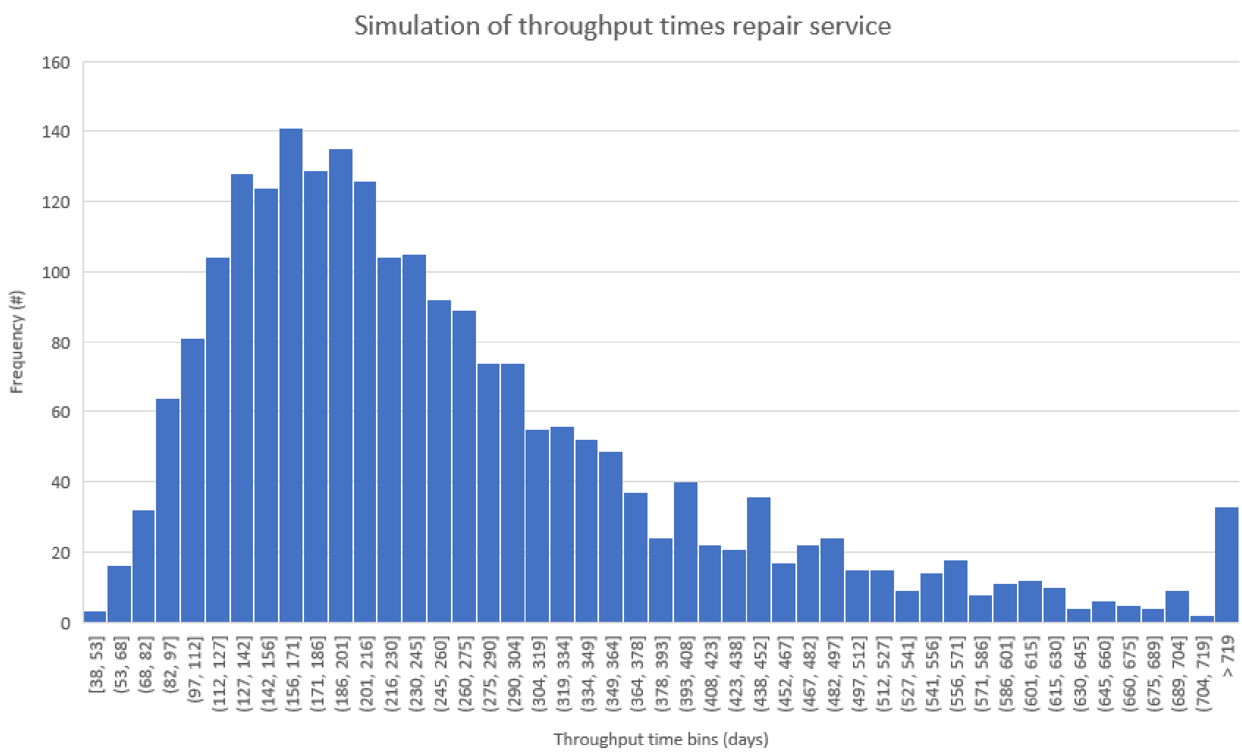

Figure 16: Simulated distribution of throughput times of the repair service with fixed price.

These interventions contribute to a decrease in throughput time because certain phases in the repair process are shortened and therefore waiting times are decreased. Another positive influence is the increase in on-time delivery. Due to these interventions, the repair service is more predictable. When it is easier to predict this service, a more reliable promise date can be issued to the customer, resulting in a higher on-time delivery performance.

4.4 Conclusion

After looking into interventions, the loan-item, inventory, and fixed price intervention were chosen to implement in the simulation for 9% of the repair order. These are the repair orders with a throughput time that is higher than 300 days. The results are presented in Table 13.

The characteristics of the loan-item are that it skips the process after the RMA assessment and has a standard throughput time of 60 days for 9.0% of the repair orders, this results in a mean throughput time of 240 days (37 days decrease), with a standard deviation of 162 days (5 days decrease), and a repair price of 14,250-32,500 euros.

Inventory makes sure to shorten the repair process. This intervention is also implemented for 9.0% of the repair orders, and results in a mean throughput time of 271 days (decrease of 6 days), with a standard deviation of 157 (10 days decrease), and a repair price of 4,250-12,500 euros.

The last intervention is the fixed price. This intervention skips the RfQ process, and is implemented for 9.0% of the repair orders. The mean throughput time is 264 days (13 days decrease), with a standard deviation is 161 days (6 days decrease), and a repair price of 10,000 euros.

Table 13: Overview of different interventions and their variables.

Intervention	**Mean throughput time (days)**	**Standard deviation (days)**	**Costs (euros)**
Current situation	277	167	3,000-10,000 euros
Loan-item	240	162	14,250-32,500 euros
Inventory	271	157	4,250-12,500 euros
Fixed price	264	161	10,000 euros

5 Evaluating the improved concept

This chapter concludes the research of this thesis. First, the conclusions of the research are drawn and the recommendations for TNNL are listed. At last, some topics for further research are discussed. The conclusion of this thesis will give an answer to the question how to improve the end-to-end process flow of the repair service at TNNL.

5.1 Conclusions and recommendations

The current repair service has an average throughput time of 277 days with a standard deviation of 167 days. The interventions are implemented in the simulation for the most repaired products with a throughput time higher than 300 days, this would mean that 9.0% of the repairs include a loan-item.

The first intervention is a loan-item. Here, for several products a loan-item will be send to the customer when their defect product gets repaired. The time the customer is non-operational decreases to the lead time of the loan-item and decreases the non-operational time to a standard 60 days.

- The simulations showed a decrease to an average of 240 days with a standard deviation of 262 days.
- Providing loan-items is very easy to plan, so the overall on-time delivery performance would increase.
- The repair price including a loan-item increases to an amount between 14,250 euros and 32,500 euros.
- The cost price of items is between 25,000 and 50,000 euros which means that the repair price would be higher than 60% of the cost price most of the time.
- The decrease of throughput time of this intervention is not worth the costs.

The second intervention is inventory. Here, for several products there is inventory on stock to improve the throughput time of the repair process with a factor of 25%.

- The simulations showed a decrease to an average of 271 days with a standard deviation of 257 days.
- Inventory would also benefit the on-time delivery performance since inventory makes planning easier. Promise dates would be more accurate resulting in a higher on-time delivery performance.
- The repair price including inventory of components increases to an amount between 4,250 euros and 12,500 euros.
- This repair price never surpasses 60% of the cost price, so it will be worth the costs.

The third intervention is a fixed price. In the situation of a repair with a fixed price, the RfQ phase will be skipped since there is no need to work out the actual costs of the repair.

- Fixed price results in a better communication flow since the decision point of the customer agreeing on a repair is brought forward in the process. There are less cases where TNNL makes costs and the customer does not want a repair.
- A fixed price does also improve the information flow since the customer knows directly what costs are involved.
- The simulations showed a decrease to an average of 264 days with a standard deviation of 261 days.
- Due to the high variation of the repair price, this would mean that a fixed price should be close to 10,000 euros to minimize the chance of exceeding the fixed price.

All costs of the interventions are charged to the customer, so it will not impact TNNL' operations. When TNNL intervenes in the repair service and improves the average throughput time, increased costs will influence the customer satisfaction less than the improved throughput time.

The recommendations for TNNL are the following:

- Organise more time stamps in the repair service. Available data only showed four different time stamps which made it difficult to indicate where the bottleneck in the process was situated. Employees responsible for a customer group do not systematically collect their data. With more time stamps in the repair service, it would create a bigger insight in the different phases, and it would be possible to suggest a more specific intervention. The most important time stamp is the one separating the order acceptance, and the repair phase. With this time stamp, it would be clear how much time is spent in the repair phase. Right now, it is unknown. Next to this time stamp, I would suggest implementing more time stamps in the RfQ and repair phase. These are the phases where it is unclear what exactly causes delay in the process.
- Organise a way to measure the information flow. An example would be to make a checklist of information for every step in the repair process. Then, it is clear for TNNL and the customer what information is needed when. Besides this, TNNL can measure if there are steps within repair orders where there is a lack of information. This data can be analysed to see if TNNL makes any improvement in the customer satisfaction indicator information flow.
- Intervene all different customer groups. During this research, it became clear that TNNL has a great cooperation with the master customer group. The cooperation results in a very smooth repair process. Interventions and improvement in throughput time for these repairs would be less efficient than for repairs from other customer groups. However, the master customer group is involved in the majority of the repairs, and therefore intervening in the repairs from the all customer groups would have a big impact.
- The data analysis showed that some suppliers had really long throughput times. This is the result of the lack of supplier management. There are no agreements with suppliers about the lead time of repairs and the number of repairs. A recommendation would be to introduce supplier management and make agreements about lead times and amounts of repairs.

To conclude, I would suggest implementing the interventions inventory and fixed price. These two interventions could be implemented without exceeding 60% of the cost price, so TNNL's advice is to repair the item since they judge the repair worth it. The interventions show an organized repair service with a decrease in throughput times. When looking at the loan-item intervention, the costs exceed 60% of the cost price, so it is not worth to repair it. The repair price of a repair with inventory is always worth it.

Inventory and a fixed price should be implemented in the future for similar to items C, D, E, F, and G. These items have a higher throughput time than 300 days and have more than 25 repairs per year, which can give direct impact on the throughput time of the repair service at TNNL.

Table 14: Repair price of all interventions

Intervention	**Repair costs**	**Inventory costs**	**Depreciation costs**	**Total repair price**
Loan-item	3,000-10,000 euros	6,250-12,500 euros	5,000-10,000 euros	14,250-32,500 euros
Inventory	3,000-10,000 euros	1,250-2,500 euros	-	4,250-12,500 euros
Fixed price	3,000-10,000 euros	-	-	10,000 euros
Inventory & Fixed price	3,000-10,000	1,250-2,500 euros	-	11,250-12,500 euros

5.2 Further research

Next to the conclusion and recommendations earlier this chapter, there are some more interesting topics to keep in mind for further research. It would be of great value to perform a study on these topics.

In the first place, one of the customer satisfaction indicators is not measured in a reliable way. This is about the on-time delivery performance of TNNL. The reason behind this is the postponement of the promised repair return date. When anything in the planning of a repair changes due to delay, the promised date gets postponed. To do research on this customer satisfaction indicator, it should be more reliable. TNNL should keep track of the first communicated promised date. When this is organised, TNNL could study interventions to see what impact it could have on the on-time delivery performance.

Secondly, the data analysis could be more specific. I do not have the knowledge and technical to analyse what components TNNL should keep in stock. That is why the data analysis in Chapter 2 is only on product level. For further research on the inventory intervention, I would suggest finding out what exact components are often used to get to know what components should be on stock. After this, there is the possibility to calculate what the inventory levels should be.

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Appendix A: Stakeholders repair service

Based on the interviews about the current situation, I have determined the high-level stakeholders and important roles in the repair service. A stakeholder is involved with an organisation or society, and therefore has responsibilities towards the organisation or society (Cambridge Dictionary, 2019). In this context, the high-level stakeholders are the organisations that participate in the end-to-end process flow. Weske (2007) describes several types of stakeholders with different knowledge, experience, and expertise within the business process domain. I will describe the important roles in the repair service, and I will pair (if possible) the specific identified important roles of the repair service of TNNL to the stakeholders of Weske (2007).

A.1 High-level stakeholders

My focus is the end-to-end process flow of the repair service. When looking for improvements at this level, there are three stakeholders that come into play. These are the customers, TNNL, and the suppliers.

Customer

The repair service is a service to help the customer, it is centred around the customer. The customer is the stakeholder that initiates the end-to-end process flow of the repair service when one of their products from TNNL is defect. The customer cannot continue or plan their activities, so they want their defect to be repaired. However, there is not just one customer. The first layer of the customer are the people who notice the defect, they are the people on board of a naval ship. They are involved in this process because they cannot continue their activities due to the defect, so they communicate the defect to the maintenance service at the quay. This is the second layer of the customer. They replace the defect on board if the naval ship is ashore. If the last spare is used, the third layer of the customer will be involved in the process. This is the procurement department of the customer, and they will contact TNNL to initiate the repair process. During this process, there are a few contact moments; the application for an RMA, the shipment of the repair part, the agreement of the offer, and eventually the shipment of the repaired part.

Thales Naval Netherlands

The customer has the desire for a repair of one of their products, and TNNL is the service provider in this process. They are the company producing radars, sensors, and combat management systems. They want the customer to be satisfied. When the customer possesses one of TNNL's products, there might appear a defect. TNNL has a repair service for these defects and tries to satisfy the customer with this service the best they can. In this repair process, they have contact with the customer and the supplier. The supplier comes into play when the repair needs to be outsourced.

Supplier

The supplier participates often in the repair process because TNNL depends on their suppliers. The procurement department of TNNL contacts the supplier either to buy new parts or to repair parts. When the supplier executes the repair, this supplier might get in touch with their suppliers to order components for the repair. This way, a lot of suppliers could participate in the repair process. The contact moments between TNNL and the supplier are the application for an RMA, the shipment of the repair part, contact about the offer, and eventually the shipment of the repaired part.

A.2 Important roles

There are also other roles in the repair process that are very important to understand. In this subsection, the most important roles that contribute to the research are explained.

Customer Contact Centre

When the customer applies for an RMA code, they get into contact with the customer contact centre (CCC). This department is responsible for all contact with the customer, but also for the approval of the RMA application. The customer contact centre engineers (CCCEs) assess the RMA application, and when this is approved, they will send an RMA code to the customer. The sales support employees of the CCC set up the contract and send it to the customer. To conclude, the CCC delivers CCCEs and sales support employees as important roles in the repair service. They are the connection between TNNL and the customer. According to Weske (2007), these employees are knowledge workers. Knowledge workers use software systems and have detailed knowledge of the application domain. In this case, the employees process the repair into the software systems of TNNL.

Logistic centre
In the logistic centre, the repair parts enter and leave Thales Netherlands. The people working in here are the logistic engineers. They will connect the repair part in their systems to the enclosed RMA and send it to the repair shop. They are the employees who eventually send a repair part to a supplier or send the repaired part to the customer. One part of this is that the logistic engineers work with service support contracts, which makes sure that the product a customer purchases is *x%* of the time available. The logistic engineers are the process participants according to Weske (2007). They conduct the actual operational work and are helpful when modelling the process since they have a lot of knowledge about activities in the process.

Repair shop
The first step for the engineers of the repair shop is to analyse the repair part which entered TNNL. After this step, they will start the internal repair or initiate the external repair by sending it to the supplier. The last step of the work of the repair shop engineers is to test the repaired part to make sure everything works properly. The repair shop engineers are the process participants according to Weske (2007). They conduct the actual operational work and are helpful when modelling the process since they have a lot of knowledge about activities in the process. The repair shop employees have a role as process participants (Weske, 2007).

Procurement department
The procurement department is responsible for the contact with a supplier. They will contact the supplier when they need new parts for a repair or when the repair part needs to be repaired at the supplier. They need to report the costs and duration of these applications to the CCC, so they can communicate them to the customer. The procurement employees are knowledge workers since they use the software systems of TNNL to process the demands of the suppliers.

Service designers
Creating a concept of the service of Thales Netherlands is one of the main activities as a service designer. A service designer are basically the process designer that Weske (2007) describes. He explains it as the role that is responsible for modelling the business processes by communicating it to other stakeholders.

Appendix B: Explanation problem cluster

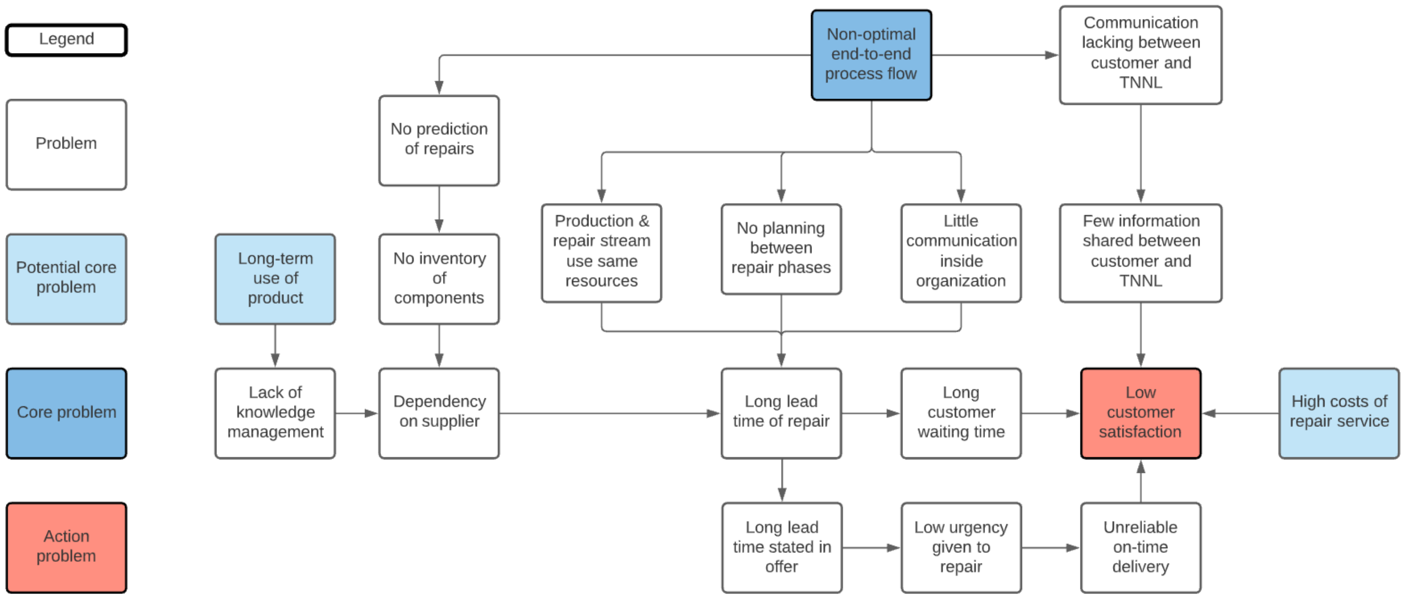

Figure 17: Problem cluster of all detected problems and their cause-effect relationship.

The customer satisfaction is negatively influenced by four problems: *'High costs of repair service'*, *'Unreliable on-time delivery'*, *'Long customer waiting time'*, and *'Few information shared between customer and TNNL'*. I will follow back these four problems to the problems which do not have a cause themselves.

Starting with the problem *'High costs of repair service'*. The potential to improve this 'cost' problem is not inside the scope of my research, so this path ends here.

The second path starts with the problem *'Unreliable on-time delivery*. The direct cause of this problem is *'Low urgency given to repair'*. Due to low urgency, it will be uncertain if the defect part will be repaired and delivered to the customer on time. The direct cause of that problem is the long-expected lead time stated in the offer. When the expected lead time of a repair is somewhere in the far future, the urgency to start with the repair will be low (repairs are not prioritised), and the repair will be postponed. This long-expected lead time, stated in the offer, is a logic effect of the actual long lead time of the repair.

Now, we have arrived at the problem *'Long lead time of repair'*, which is the direct cause of *'Long customer waiting time'* and *'Long lead time stated in offer'*. Because of the long lead time of a repair, the customer has to wait long. This is a problem for the customer since they cannot continue with their activities when their inventory is empty. The problem *'Long lead time of repair'* has four direct causes:

- The first direct cause is *'Dependency on supplier'*. Sometimes new parts need to be ordered for the repair or the repair needs to be outsourced to the supplier. TNNL often gets a low priority from the supplier, due to high diversity and low amounts of new parts or repairs. This step costs a lot of time, resulting in a long lead time of repair. This *'Dependency on supplier'* is an effect of two different problems:

  - *'Low knowledge assurance'* is the problem why certain repairs are being outsourced. The direct cause of this problem is the long-term use of the products TNNL produces. A radar might be used for over thirty years. The employees that know everything of these radars and especially how to repair these, could be retired. Therefore, the knowledge has disappeared.
  - *'No inventory of components'* is a problem where TNNL has to order new components for a repair after it has been analysed. The direct cause of this problem is the lack of prediction of repairs at TNNL. However, there is historical data of all repairs that TNNL executes.
- The second direct cause is *'Production & repair stream use same resources'*. The resources TNNL uses for production and repairs are the same. In practice, production processes go almost always first, because these processes are involved with much more money. Therefore, a repair process could be waiting long before it can start.
- The third direct cause of the long lead time of a repair is *'No planning between repair phases'*. There is an expected lead time stated for each repair, however employees do not have a planning or order that states what repair they need to work on. Therefore, a repair could be waiting long before employees start working on it.
- The last direct cause of the long lead time of the repair is *'Little communication inside organization'*. This means that departments only look at their own tasks and do not work together with other departments. Therefore, every department has its own interpretation of the repair process and the problems inside this process. The departments have little communication with each other to improve the repair process and to let the process flow smoothly.

The last three direct causes of *'Long lead time of repair'* are, together with *'No prediction of repairs'*, *'Communication lacking between customer and TNNL'* and *'Few information shared between customer and TNNL'*, problems that arise from the problem *'Non-optimal end-to-end process flow'*. The little communication between the customer and us consists of the few contact moments with the customer. TNNL will not actively approach the customer to send their defect parts or to accept their offer. A different example is receiving repairs, which eventually cannot be repaired or do not have a return merchandise authorization (RMA) number attached to itself. From this problem, the problem *'Few information shared between customer and TNNL'* arises. This consists of the customer not receiving the information about the repair and TNNL not receiving information about the origin of the defect. The information is not communicated with the customer.

The problem *'Non-optimal end-to-end process flow'* has no direct cause. This process does not run smoothly, effecting the five problems mentioned in the paragraph above. This path ends here.

Appendix C: Modelling a process

C.1 The research question

The research question I will solve by means of a systematic literature review, is research question 1b: *'How can I model a clear overview of the current repair service?'*

C.2 Integration of the theory

To solve the research question *'How can I model a clear overview of the current repair service?'*, the literature describes different ways of modelling a process. I have put these methods of modelling next to each other and will make a conclusion at the end. Another process of TNNL, the spares process, is very similar to the repair service. I found out that this process is already modelled in one of the systems of TNNL as a business process modelling notation (BPMN). That is why I have decided to dive more specifically in this kind of modelling.

Context diagram

A context diagram is a very general way of modelling a process. It illustrates the relationships of a process in one environment and the relationships with entities from outside (Wibawa et al., 2019). It is not possible to model a detailed process with this diagram.

Data flow diagram

A data flow diagram describes a system as a network of processes that is connected by data. It is often used, when the system's functions are important to manipulate the data (Wibawa et al., 2019). Teixeira et al. (2018) states that this method is very useful in understanding a process when analysing it. The flows of data between different processes are highlighted in these models.

Entity relationship diagram (ERD)

An ERD describes the relationships between different entities in a process. It is a more complex way of modelling than in a context diagram, since it also describes relationships of entities that have attributes with other entities in an integrated system. ERDs are used to model the data to develop a database with (Wibawa et al., 2019).

Relational model according to Francik et al. (2018)

The diagrams described above, are all relational models. Francik et al. (2018) describes the three stages to create a relational model as follows: Firstly, an analysis of the system and its structure is performed. Here, all relevant components and actions are modelled in a diagram to see what happens where in the process. Next, a representation of selected system objects as model elements is made. This stage is supposed to make assumptions where possible to simplify the structure of the process. Also, the important objects of the process to function properly are selected. When combining only the important objects and the assumptions, the complex process is simplified. The last step is the creation of the relational model. The relational structure can be modelled as a matrix or graph where only the relations are visual by 0 or 1, or by arrows.

Unified Modelling Language (UML)

UML specifies, visualises, construct and documents artefacts of software systems. For every dynamic aspect of the system, it shows a different diagram. An example is the activity diagram, which shows the flow between activities. This diagram is often used to model business process and to describe the activities taking place. However, certain aspects of a business model are not mappable in an activity diagram, often an extension to UML is used to cover that (Teixeira et al., 2018).

Business process modelling notation (BPMN)

Liew et al. (2005) writes that BPMN has its goal to be easily understandable and easily use by process creators, implementers, or managers. It is a method which uses flowcharts to create a visualization of business process operations. It uses the following objects (Liew et al., 2005):

- Flow objects: event (what happens during the process and effects the flow), activity (atomic or non-atomic thing, describing the work of a company) and gateway (controls divergence or convergence of flow)
- Connecting objects: sequence flow (shows order of activities), message flow (shows messages sent between participants of process) and association (associates information with flow objects)
- Swim lanes: pool (partitions activities or represents a participant) and lane (used to sub-partition a pool)
- Artefacts: data object (show in-/output of activities), group (used for analysis or documentation) and annotation (method to provide additional information to modellers)

Trkman et al. (2016) uses user stories to strengthen the message of a business process model. First it collects all user stories. After this step, these stories can be implemented at the activity objects from a business process model to add value.

To conclude, business process modelling notation is the most inclusive and detailed method of modelling. It does not provide elements that describe data structures or language for data manipulation (Teixeira et al., 2018), but that is not necessary to model the repair service at TNNL. With the ability to model the complex repair service, BPMN is complete enough. Besides this, BPMN clearly visualises the context of activities in pools and lanes, like the different departments of TNNL, the supplier, and the customer.

C.3 Terminology BPMN

Liew et al. (2005) write that BPMN has its goal to be easily understandable and easy to use by process creators, implementers, or managers. It is a method that uses flowcharts to create a visualization of business process operations. It uses the following objects (Liew et al., 2005):

- Flow objects:
    - Event: effects the flow.
    - Activity: is a (non-)atomic object.
    - Gateway: controls divergence or convergence of flow.
- Connecting objects:
    - Sequence flow: shows the order of activities.
    - Message flow: shows messages sent between participants of process.
    - Association: associates information with flow objects.
- Swim lanes:
    - Pool: partitions activities or represents a participant.

    - Lane: is used to sub-partition a pool.
- Artefacts:
    - Data object: shows in-/output of activities.
    - Group: is used for analysis or documentation.
    - Annotation: is a method to provide additional information to modellers.

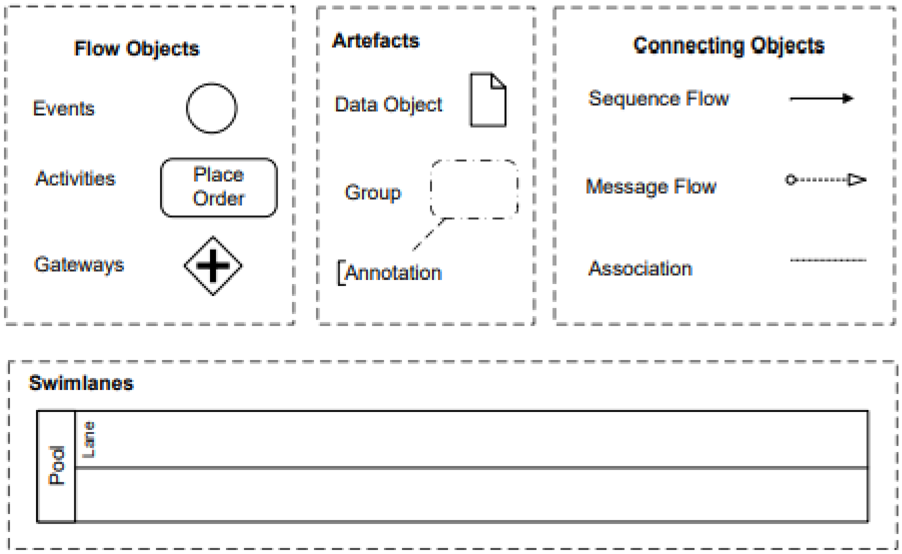

Figure 18: Categories of objects in BPMN (Weske, 2007)

Event is an object that represents what happens during a process and it is an object that affects the flow. Events can be divided into three types: the start, intermediate, and end event (Weske, 2007). Respectively, they can trigger, delay, or terminate processes. On the other hand, events can be triggered by a user, a message, a specific date, a rule, an error, a link between an end of a process to the start of another, or a combination of these (multiple). These difference between events are all modelled differently, as it can be seen in Figure 18.

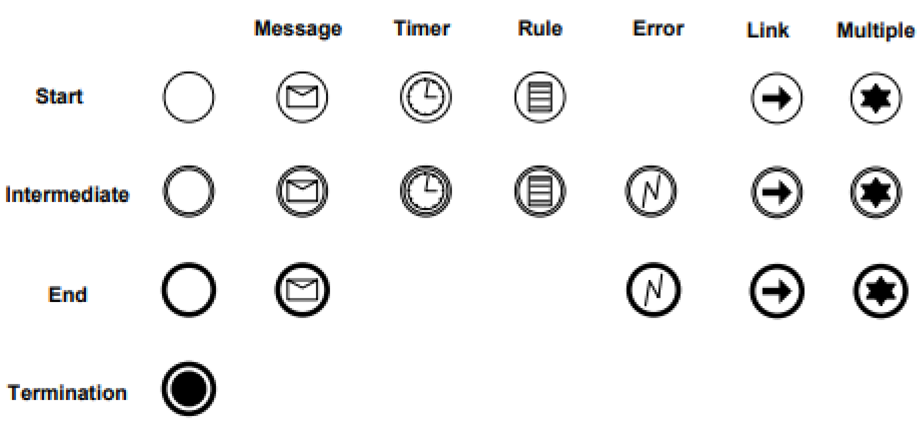

Figure 19: Event types in BPMN (Weske, 2007)

Activity is an object in BPMN that is an atomic or non-atomic thing, it describes the work of a company/process. Atomic activities are also called tasks, non-atomic activities are subprocesses. Subprocesses are modelled just like atomic activities however, they can be expended in such a way that the expansion is a process itself (Wekse, 2007). Atomic activities can be divided into receive and send tasks (regarding a message), service tasks, user tasks (user-interaction), manual tasks, and script tasks (depend on tool support). Stachecki (2016) also describes the business rule task which provides input and output of a business rules engine. These tasks are visualised in Figure 19.

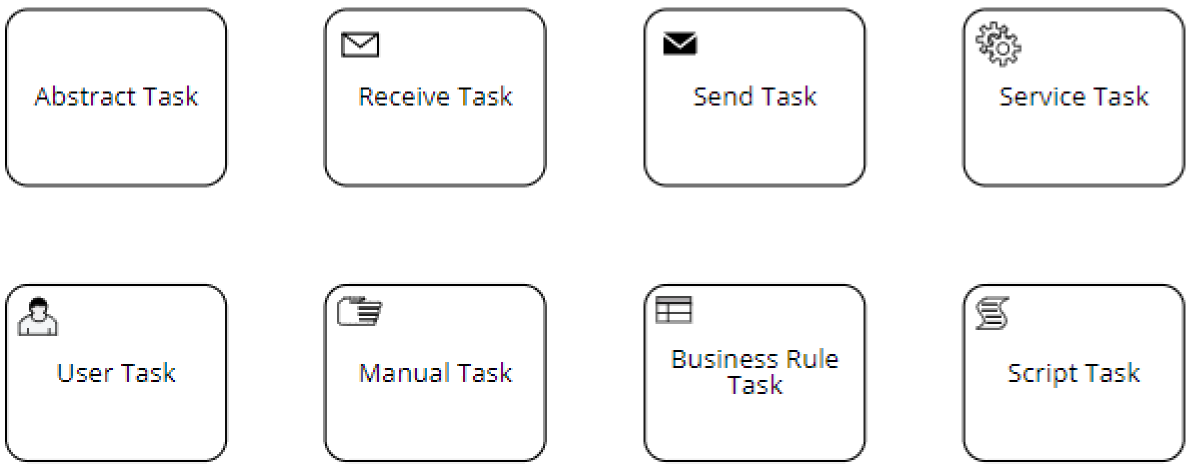

Figure 20: Task types in BPMN (Stachecki, 2016)

Gateways act as a join or split node. Weske (2007) divides the gateways into several types, as Figure 20 shows. The first one he defines is the data-based exclusive or split. Based on data it decides which path to follow. An event-based exclusive or gateway makes a decision based on the completion of events. The inclusive or gateway (OR) selects an arbitrary number of outgoing paths however, at least and only one path can be chosen. Meanwhile, the complex gateway can combine different paths to be executed. The AND gateway obligates the process to choose all outgoing paths and to join all incoming paths.

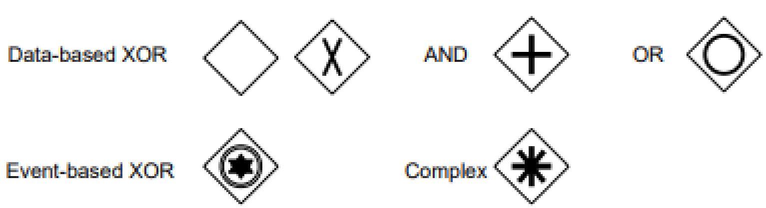

Figure 21: Gateway types in BPMN (Weske, 2007)

Sequence flows are visualised by solid arrows between activities, events, and gateways. A 'normal' flow starts at the start event and follows a set of flow objects until arriving at the end event. An exception flow is another type of sequence flow. This flow starts at an intermediate event at the boundary of an activity. The intermediate event will generate the exception flow only if the activity, to which it is attached, is active. For example, the following situation, an intermediate timer event of one hour is attached to a brainstorm activity. When this time exceeds one hour, this intermediate event is created, the brainstorm activity is completed, and the process continues (Weske, 2007).

To conclude, I defined the most important object in BPMN to create a valuable visualization of the current repair process at TNNL. When combining all these objects a business process model, like Figure 21 shows, can be modelled.

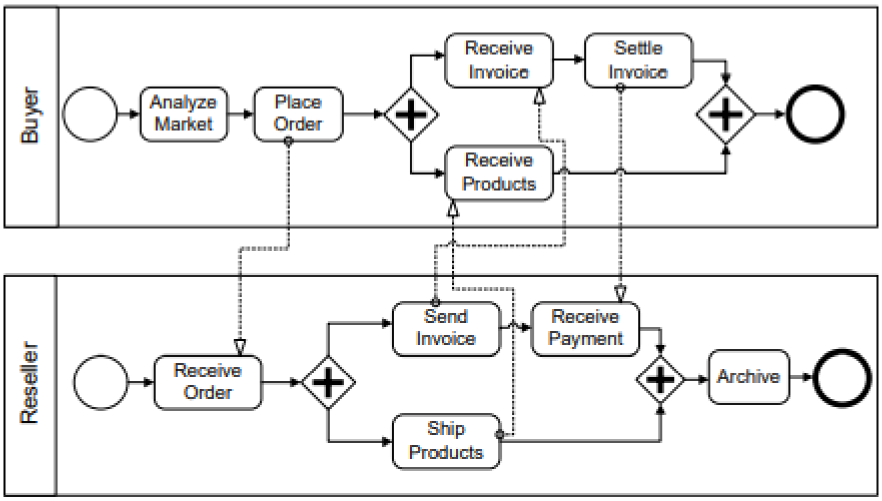

Figure 22: A business process model involving a buyer and reseller (Weske, 2007)

Appendix D: Theoretical framework RCA

The 3 x 5 why's technique is derived from the 5 why's method, which is a method to find cause-effect relationships in a problem. It uses the question, "Why?", repeatedly to peel away all issues and symptoms. Eventually, the root causes become clear. However, when executing this methodology, one or more why's could split up in their own 5 why's branch, addressing other issues contributing to the problem. These issues can be classified with the terms occurrence, human, and system (Gangidi, 2019). This is visible in Figure 22.

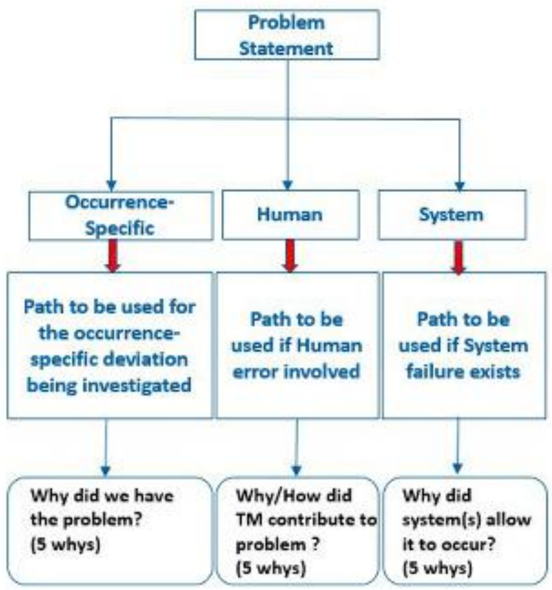

Figure 23: 3 x 5 why's technique (Gangidi, 2019)

Occurrence is the term to describe the 5 why's track where all issues are man-, machine-, measurement-, and material-related. The question to ask is, "Why did we have the specific deviation?". Mostly, quality issues start with this question, but as we proceed through the 5 why's, there might be points where we can continue with other paths where human or system contributions are treated. The root cause in the 5 why's related to occurrence, is often about the design and/or operations of the process (Gangidi, 2019).

Human is the second term to classify issues. The question to ask in this situation is, "Why or how did the team member contribute to the problem?" The root cause is in most cases a human error, for example lack of assertiveness, lack of resources, lack of communication, or lack of knowledge (Gangidi, 2019).

System is the third and final term to classify issues, where the root cause is typically related to management or quality system issues (methods and environment). Often, this can be traceable to/controllable by support people. The why-question related to system is, "Why did our system allow the problem to occur?"

Appendix E: Bottlenecks repair process

In this research, one of the questions is: “What are the biggest bottlenecks in the repair service?” We want to improve the end-to-end process flow of the repair service to improve the customer satisfaction. So, we have to look at the bottlenecks that suppress the customer satisfaction. More important is to look for the part in the process that contributes the most to customer satisfaction, and improve this.

I have already identified the majority of the problems in the repair service in the previous chapter. These are:

Monopolistic behaviour

TNNL was a company that produced everything by themselves. Over the past decades, TNNL innovated and started focussing more and more on high-end productions. This meant that more knowledge was needed for their products, and it was more beneficial to outsource several steps of the production process. TNNL has always been one of the biggest companies within their market, and because of this they show monopolistic behaviour. This behaviour manifests itself in the reactive attitude of TNNL. The approach of their activities is reactive. Examples are the little communication with the customer and the low amount of information about the repair and the service being shared with the customer.

Decision-making is not organised on a high level of organisation

TNNL has several streams within the company. Two of these are productions and repairs. Due to the fact that these two use the same resources, there is a difference in priority. Productions get a higher priority because there is more money involved in productions than in repairs. However, there is no clear strategy or management in this area. The decisions within the priority area are taken based on incidents, which is not efficient. The decisions about priority are not made on a high level of the organisation, therefore not all consequences are included in the decisions.

There are no criteria for repairs when entering the service

TNNL is in most cases of a repair dependent on a supplier. Either, the supplier has to execute the repair, or the supplier has to deliver components to TNNL, so they can finish the repair. However, TNNL has many suppliers, so the orders have a high diversity and a low amount. For the supplier, Thales Netherland is a very small customer, so the orders will not be prioritised. There are no agreements between TNNL and the suppliers to increase this priority in order to be more efficient and reliable to the customer.

The difficulty within this problem is the high diversity and low amount of an order. For all different products, repairs are executed. This results in such a high diversity and makes repairs less predictable. There are no repair criteria that says which products should be included or excluded for repairs to make the repair service more efficient.

Lack of communication, since there is not one person responsible for whole repair service

The process right now consists of too many loose parts, there is little cohesion and communication between the departments within TNNL. This results in hiccups in the process that contribute negatively to the lead times and on-time delivery. Nobody is responsible for the whole repair process and therefore nobody takes responsibility.

Inventory management has not been fully implemented

As already discussed, the repair service of TNNL often depends on a supplier. This dependency has two causes. The lack of inventory management and knowledge assurance. Currently, in the planning of a repair there are some exceptional cases where there are some components on stock. But overall, there is no structural inventory management. This results in a situation where TNNL has to order several components after the customer has agreed on the offer. Obviously, with this fact, the lead time of the repair process is very long.

The lack of knowledge management

TNNL produces products with a lifespan of decades. When a product of thirty years returns for a repair, it could happen that the knowledge to repair it has disappeared. In some cases, this results in a lot of inspection costs, or the repair should be outsourced to a supplier that has very specific knowledge about the product.

Appendix F: Goodness-of-fit test RfQ

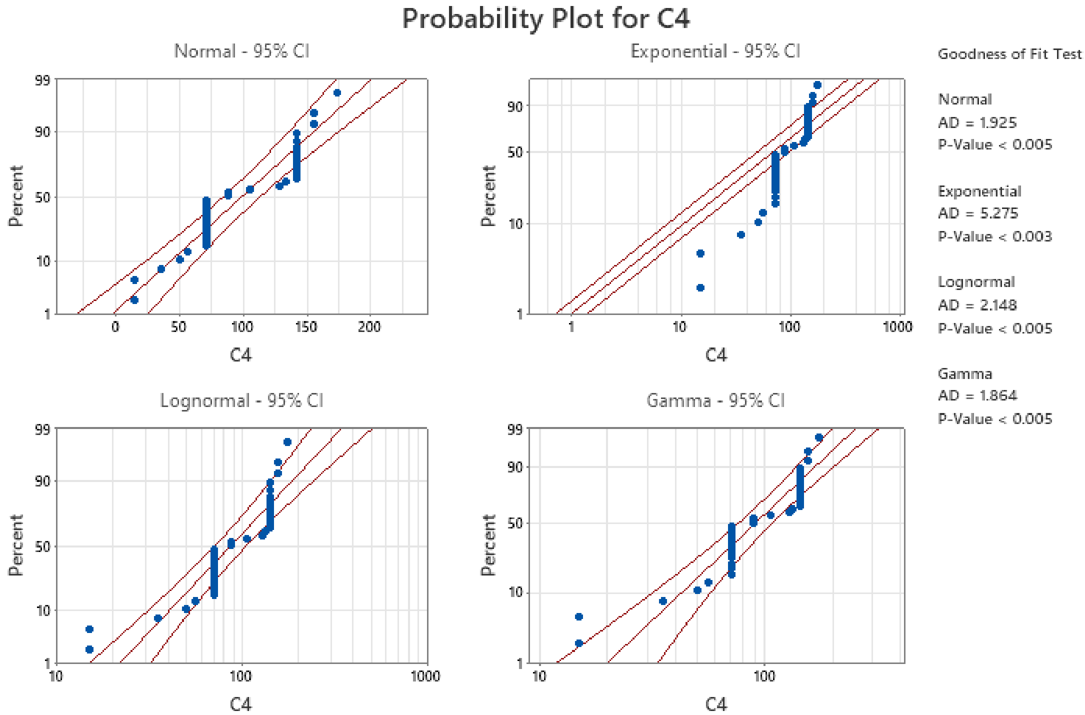

Figure 24: Goodness-of-fit test RfQ phase of master group.

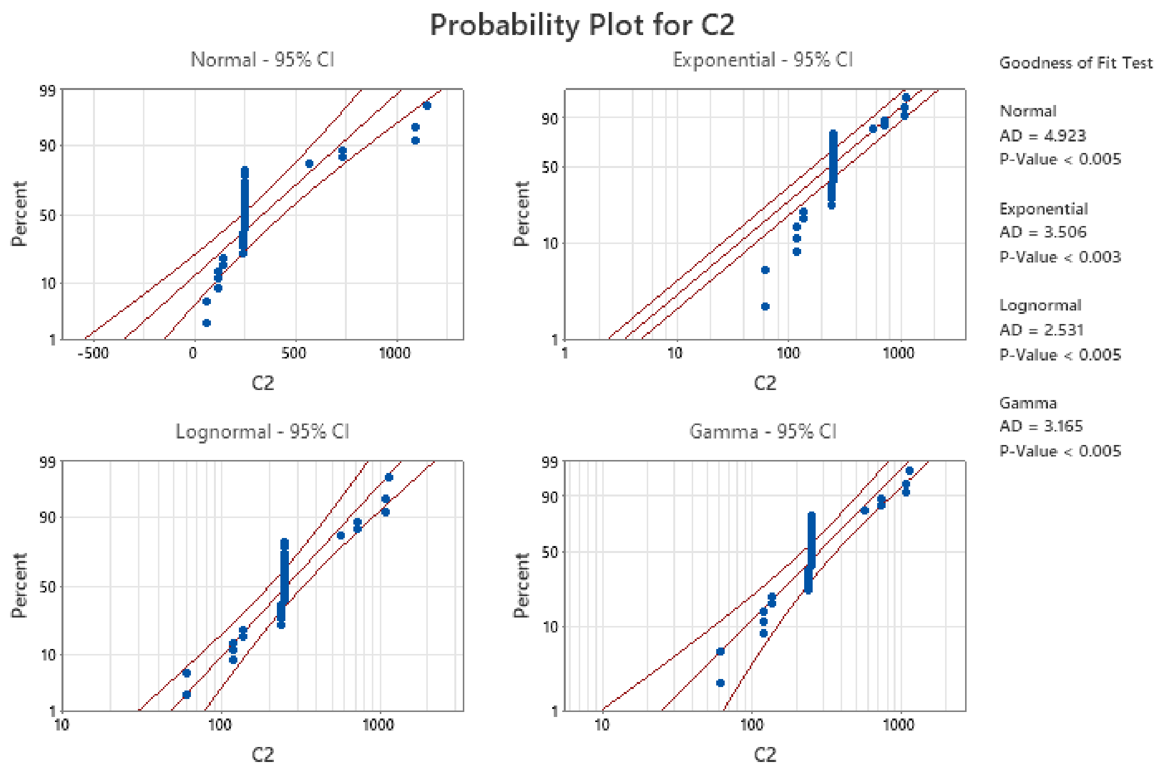

Figure 25: Goodness-of-fit test RfQ phase of investor group.

Appendix G: Goodness-of-fit test order acceptance and repair phase

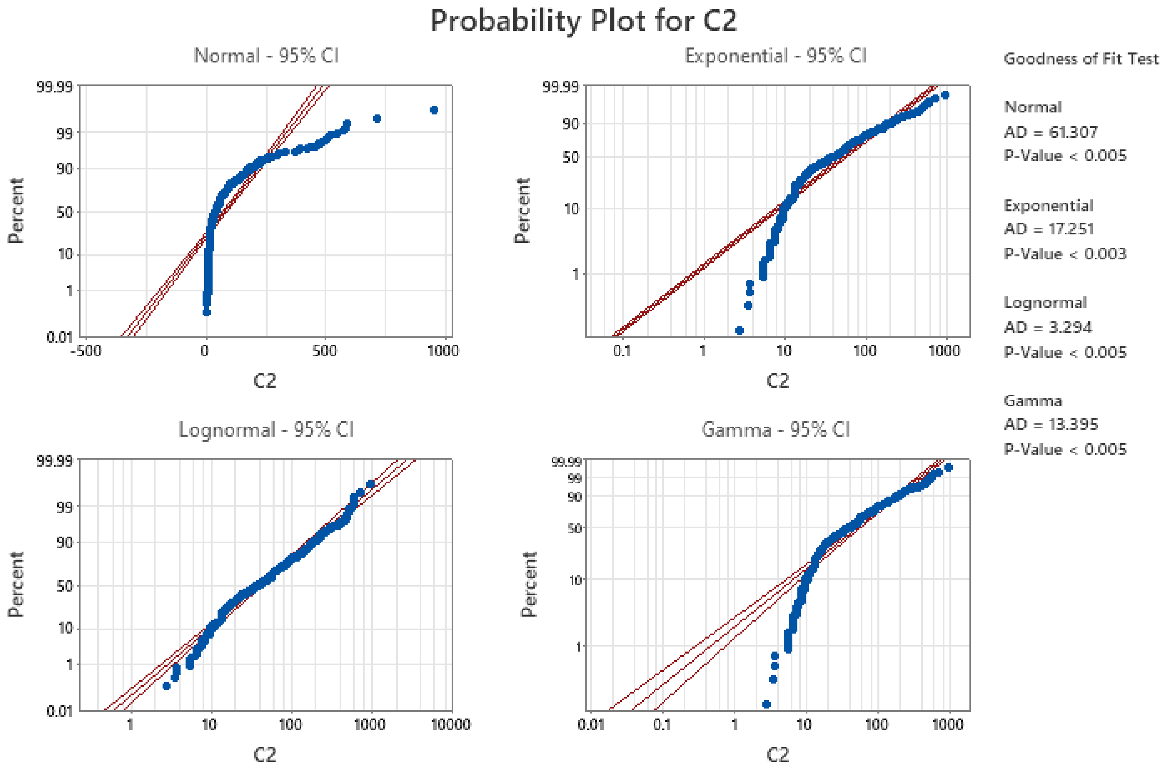

Figure 26: Goodness-of-fit test order + repair phase of master group.

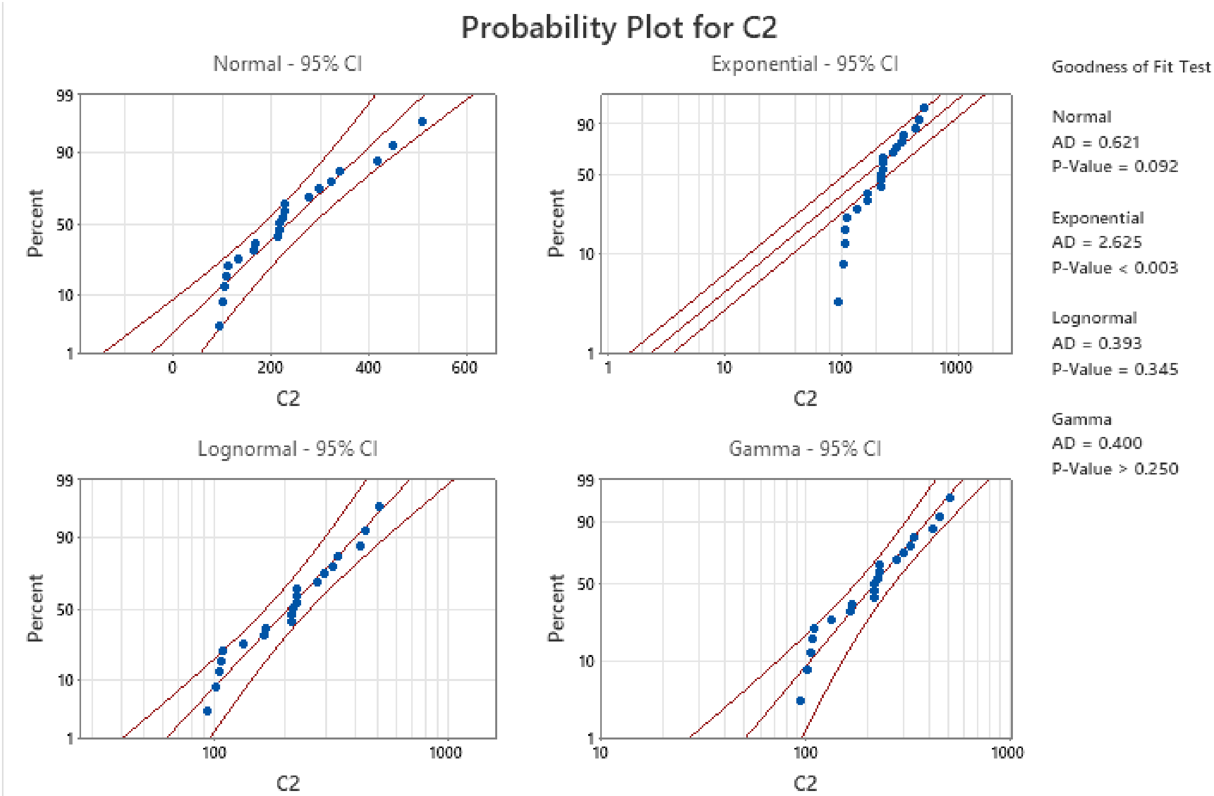

Figure 27: Goodness-of-fit test order + repair phase of investor group.

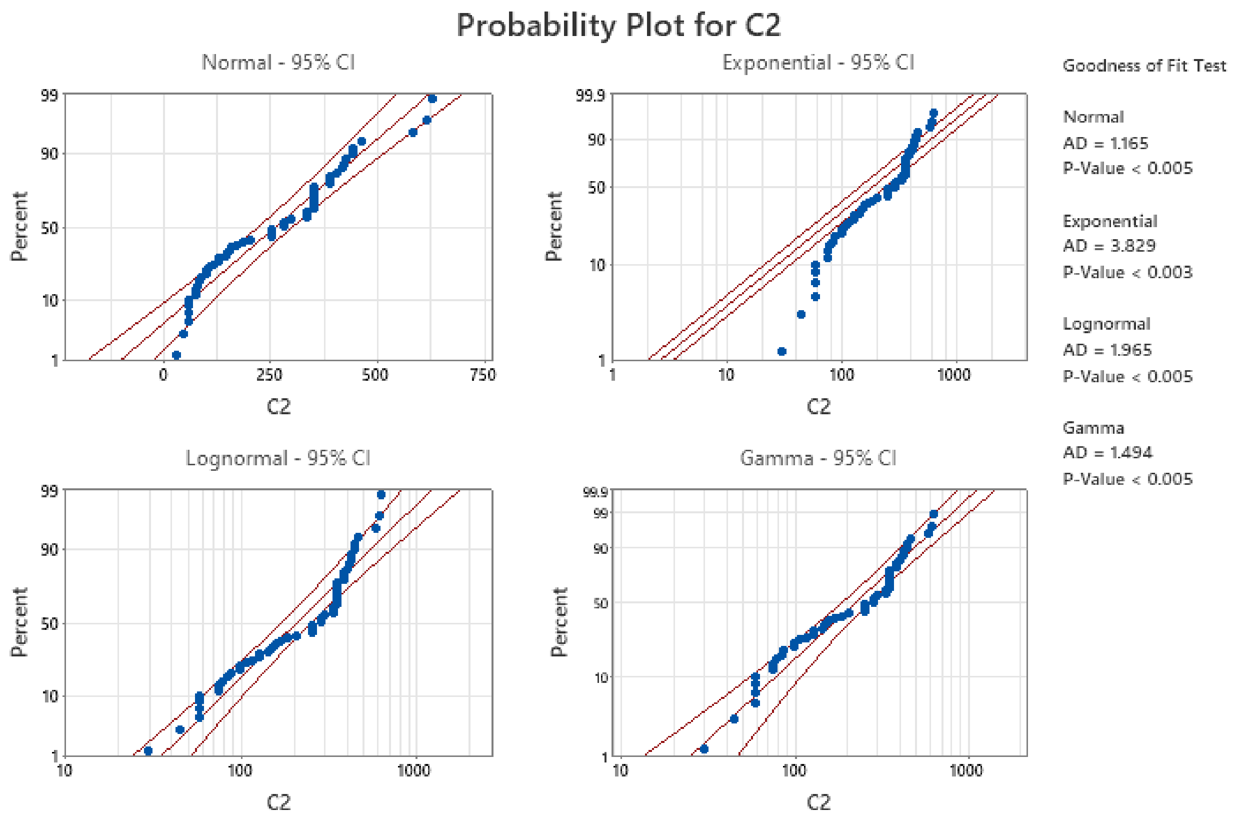

Figure 28: Goodness-of-fit test order + repair phase of executor group.