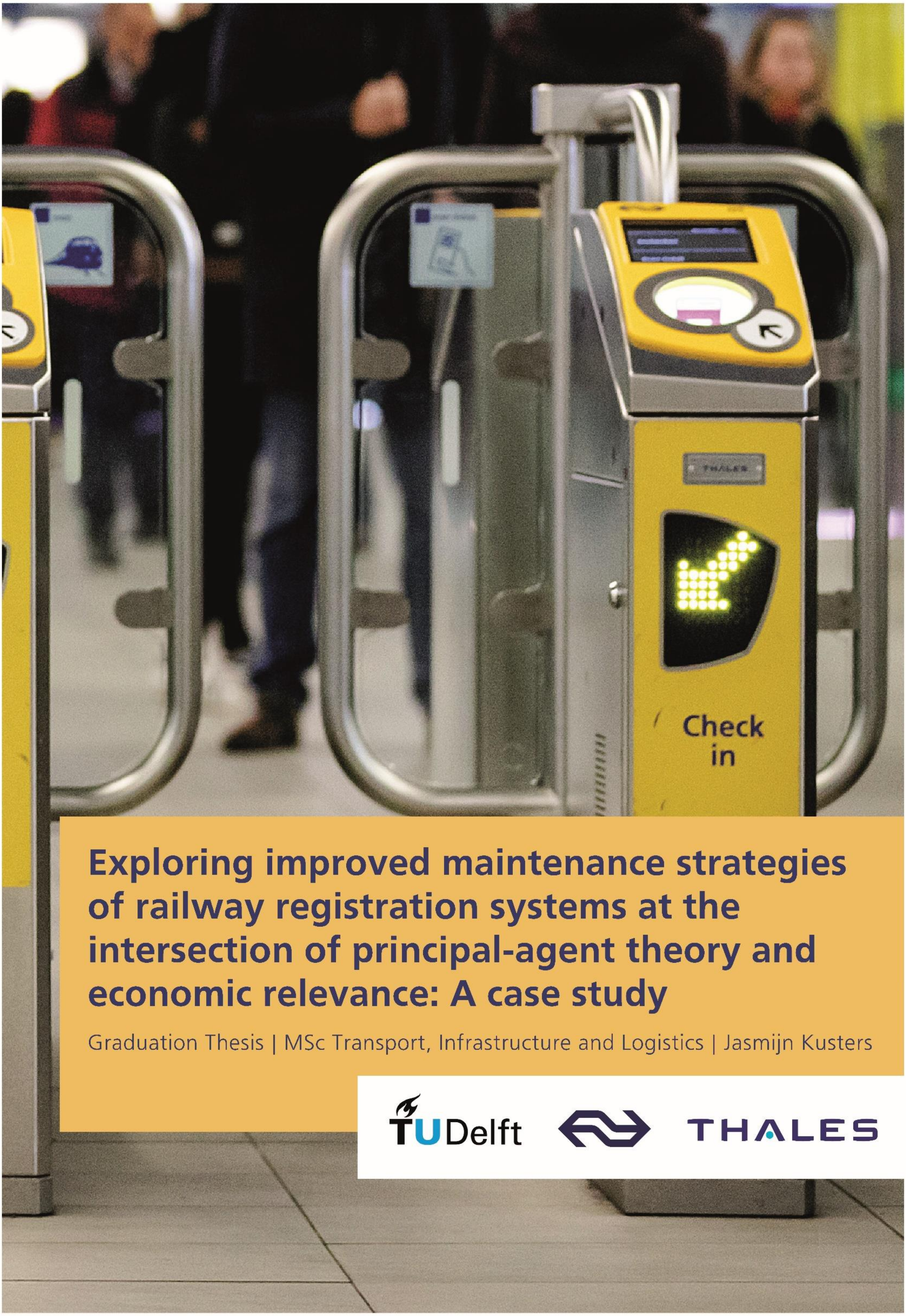

Exploring improved maintenance strategies of railway registration systems at the intersection of principal-agent theory and economic relevance: A case study

Graduation Thesis | MSc Transport, Infrastructure and Logistics | Jasmijn Kusters

TU Delft
THALES

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A CASE STUDY AT THE NS AND THALES

Master thesis submitted to Delft University of Technology in partial fulfilment of the requirements for the degree of

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By

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Preface

More than a million people travel by train every day and occasionally I am one of them. Fortunately, I have never experienced any inconvenience due to malfunctions of the station resources. But the fact that I, the traveller, am one of the main actors in this research, makes this research very concrete. I found this one of the nicest things about my research topic.

Since November 2018 I have been working on this master thesis as the final project of the master Transport Infrastructure and Logistics at the Delft University of Technology. The research is conducted in cooperation with Delft University of Technology, NS BSM and Thales Ticketing Service. In the period I have been working on this report, several people have been of added value for me. That is why I would like to thank them before you start reading my thesis.

First, Astrid and Natasja from the NS and Thales, they gave me the opportunity to carry out an unique project, because I was allowed to work with both the client and the contractor of the maintenance process of the station resources. Thank you for the good and personal guidance you have given me during this half year. Unfortunately, Natasja has not been able to complete the project, but that is why I would like to thank Willem Knol as well, for taking over her guidance and the valuable feedback he has given at the end of my graduation period.

Both the NS and Thales have opened the doors of their organisation to me. It was possible to look at all the processes and talk to anyone relevant to my research. A day on the road with Rachid Ainaou, a mechanic at Thales, was one of my favourite experiences. So nice to see the passion each time he has to resolve an incident.

From the university, I want to thank Jan Anne Annema and Jaap Vleugel for the supervision. Even though the both of you have a lot of students to supervise, there always was the possibility to receive guidance when necessary. I appreciated the personal way of coaching and the help structuring my research. I often had in mind how to approach things, but you made sure that it resulted in a proper thesis document. I also want to thank Bert van Wee for being my chairman, you made sure that during the official contact moments there always was a fresh and critical feedback, which kept me sharp.

And last, but certainly not least, I want to thank Ties, my parents and all my friends, from which I received overwhelming support during the entire process. There were ups and downs, but you made sure that I quickly found my motivation and inspiration back, so that I managed to meet my tight graduation deadline.

This report finalises my years as a student, which on the one hand is regrettable, because this period has given me a lot of opportunities and has learned me a lot. On the other hand, it is also great to close this chapter. I’m now looking forward to find a challenging work environment where I can apply the knowledge I have acquired.

Jasmijn Kusters
Delft, April 2019

Executive summary

Since 2011, an electronic registration system, called the OV chip card, has been used in the Netherlands for the payment of all public transport. As a result, the Dutch Railways (NS) have implemented all the necessary equipment to support the sales and validation processes. Thales maintains all sales and validation resources on behalf of the NS. The maintenance provisions are captured in two contracts; the OVCP full-service contract for the gates and the CiCos and the TODI contract for the ticket vending machines, ticket service desks and the information and alarm columns, where Thales is paid for each repair carried out by a mechanic. Both contracts are constructed primarily on a reactive maintenance strategy.

Currently, all the station resources within the scope of this research have an availability of at least 99%. However, on average of 300 disturbances a week occur, which cause significant inconvenience for the traveller and incur costs for both the NS and Thales. Any disturbance should be placed in a context in order to validate the impact for the traveller. In some cases the impact can be huge and in other cases a disturbance may not influence travellers comfort at all. Hence, the reported 99% availability of the station resources can lead to a distorted picture. This has resulted in the following research question:

How can the maintenance process of the station resources of the NS and Thales be improved without negatively impacting travellers' experience?

In order to answer this research question, firstly the scientific fields of the principal-agent theory, the economic relevance of maintenance, different maintenance strategies and the definition of efficiency in maintenance were analysed. This provides a starting point in terms of knowledge and insights for the further research. Secondly, the research focused on the current maintenance situation by observations and interviews with experts, as well as with the executive people from both NS and Thales. This included the planner, qualifier and mechanic at Thales and the employees of the Operation Centre at the NS. In addition, data analysis was carried out to gain a better understanding of the meaning of a failure.

Based on these analyses, inefficiencies, also known as waste, of scarce resources such as time, money, physical materials and personnel, are determined. It appeared that a flawed maintenance strategy, unnecessary repetitions and negligence by employees at both NS and Thales caused the main inefficiencies in the process.

Additionally, issues arose from the principal-agent relationship between the NS and Thales, such as lack of trust. The principal-agent theory explains that actors are self-interested and thus seek to maximise their own welfare. The principal does not know whether the agent will perform optimally and both the agent and the principal usually lack sufficient information about each other services. This can result in power imbalances, trust issues and the lack of willingness of partners to change behaviour in favour of the other party. In the context of this research, the NS is the principal and Thales the agent of the collaboration. Trust issues, in particular, were indeed found to be poignant as the NS does not believe that Thales is acting in a manner consistent with the primary objective of giving the traveller a pleasant journey. Thales in turn argues that they are not able to act according to the wishes of the traveller because the contract with the current Service Level Agreements (SLAs) is the assessment criterion, and therefore does not provide a good incentive for the desired behaviour.

Due to the inefficiencies that occur in the maintenance process of the station resources, the requirements from the main actors are not met, i.e. a low number of (repeat) failures, a high equipment availability, a low dissolution time, low equipment-, transportation- and staff costs and high

customer experience. Consequently, this research has analysed potential solutions to prevent these inefficiencies in the future.

From the literature, but also from knowledge gained in this case study, it can be concluded that it is crucial that solutions aim to reach an economic relevance optimum. However, this study also shows that collaboration is an essential factor, which can undermine efficiency. Hence, it is critical that potential solutions account for this as well. To increase economic relevance, it is important that the process is efficient and the waste is minimised. In this case study, customer experience will be increased when the principal-agent collaboration is improved. Figure A shows how these aspects are interrelated in this case study and could be applied to other maintenance improvements in comparable maintenance fields. There are, in no particular order, four general aspects in the circles that have emerged from this study as being the most important for approaching good economic relevance and customer experience. The right maintenance strategy should be applied, there should be no unnecessary steps in the maintenance process, there should be transparency in the process and in data about failures, both at the principal and the agent side of the process, and lastly it is important that failures are resolved on the basis of demand-driven failure prioritisation.

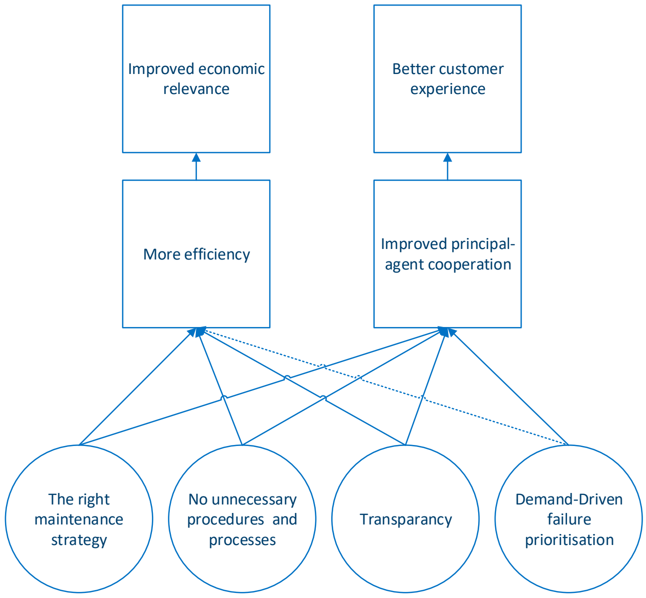

Figure A, Concluded relation between scientific concepts

It differs per maintenance field how these four aspects must be organized exactly. For this case study, the literature shows that a different maintenance strategy should be applied to the maintenance of the station resources of the NS. Reactive maintenance, which is currently primarily applied, has many disadvantages, including unpredictability, high costs and an inefficient use of staff. It is therefore proposed to implement a preventive maintenance strategy and, in the long term, move toward a predictive maintenance strategy. One of the advantages of periodic (preventive and predictive) maintenance is less inconvenience to the traveller compared to reactive maintenance, as it can take place at favourable times and the dissolution time is shorter. In addition, predictive maintenance allows the lifetime of equipment to be more accurately determined, resulting in the optimization of the economic relevance. The explanation for this occurrence is that maintenance is performed at the correct time and the equipment is only replaced when it has been demonstrated that it will fail soon. As a result, the NS and Thales do not have to carry out excessive maintenance. This will lower the (equipment) costs, compared to preventative maintenance, where equipment may be replaced prematurely. This means no economic optimum has been achieved according to the economic theory.

At present, 1 in 6 maintenance work is proactive and the rest is reactive maintenance. When proactive maintenance is mainly adjusted, the ratio will adjust and less reactive maintenance is required. As a result, the disadvantages of reactive maintenance will occur less and the benefits of proactive maintenance will become ever greater. However, reactive maintenance will always be needed, because as literature and experiences from this maintenance field indicate, it is just not possible to prevent all incidents.

That is why this research also investigates the current process to prevent inefficiencies for the future. Firstly, it examined whether repeated and unnecessary processes could be avoided. On the one hand, this requires adjustments to the current process. For example, unnecessary telephone contact between the mechanic and the NS must be avoided and the physical booklet that keeps track of the work done on a piece of equipment must be removed. This creates one central location with all the information on failures in Service Now, instead of the information asymmetry that occurs when information is distributed across multiple locations and platforms. Next to that, adjustments to the existing systems such as Service Now and the CMDB have to be made to prevent processes being duplicated, but most importantly, there must be more transparency in data. Data about all the failures at the station resources of both Thales and the NS reboots, but also user data. When more transparency is provided in the failure data and with the prevention of duplicate and unnecessary processes, people from both the NS and Thales have more time to do better analyses of failures that occur. As a result lessons will be learnt from the (repeated) failures that have taken place, and a preventative strategy can be put in place. This ultimately means that the traveller experiences less nuisance and has a better customer experience.

The service of Thales becomes even better if they act more in line with the current needs of the traveller. This can best be achieved by considering the urgency of the fault, as well as the actual fault when prioritising repairs. As a result, disruptions with a high urgency are resolved faster than a disruption at, for example, one gate within a row of 20 alternatives. Here all the requirements of the traveller are met, such as no waiting time and a safe situation. According to this approach, Thales takes the needs of the traveller increasingly into account, making the NS more trustful about the service that Thales provides and creating a better customer experience.

In order to successfully implement the four proposed solution directions, the current contract must be adjusted. When different failures priorities must be taken into account, other Service Level Agreements must also be linked to them. Failures with a high priority must be resolved as quickly as possible, while failures with a low priority can have a longer resolution time, giving Thales the opportunity to plan more repairs efficiently, which will reduce both the transport and personnel costs. Also, the concept of customer experience must be added in the contract as a Key Performance Indicator (KPI). In the current situation, solely the availability of equipment is considered, while in future a slight decrease of the equipment availability, as a result of higher customer experience, will have more limited negative side effects. Moreover, it is best if all resources are covered by a full-service contract. This should result in the desired incentive to be more efficient on Thales' side, because efficiently resolved problems will directly turn into profit and enhance travellers' experience.

It can be concluded from this research, when optimisation of maintenance processes is considered, it is necessary to examine solutions which can improve both the economic relevance and the principal-agent cooperation. Typically efficiencies are only judged on economic relevance but also a hampering collaboration between parties can still cause inefficiencies. Improvements in the maintenance process must therefore also focus on softer factors such as improving trust and transparency.

The literature research that has been done for this research also shows that there is little scientific literature on maintenance strategies that, in addition to technical and economic aspects, address the importance of these softer factors. This research shows that this softer side of the collaboration is essential, and therefore provides an addition to the existing literature. Although this has only been demonstrated within one case, much scientific literature refers to principal-agent issues in different fields. However, this has previously not been linked to maintenance processes. But it is likely that the issues due to the principal-agent cooperation also occur here.

From this research there are three steps for further research. Firstly, more extensive research should be done into the actual inconvenience of disruptions to station resources by the traveller. Then it can be validated in the future whether the improvements to the process actually have an effect. Secondly, further research should be carried out to specify the demand driven failure prioritization. This research has shown that this will have a major improvement on the customer experience, but research still needs to be done into how this should be implemented. Lastly, it is stated that there should be more transparency in data. However, research need to find out which data is relevant, because a lot of data does not provide transparency, but smart data does.

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Terms and abbreviations

Terms

Configuration Item	-	Equipment item, like a certain gate or CiCo
Failure	-	Malfunction where equipment no longer functions properly
Mechanic	-	Employee of Thales who resolves the failures and performs periodic maintenance
Planner	-	Employee of Thales who assigns the work to the mechanics
Operation Centre NS	-	Department of the BSM NS where all failures are monitored
Station Resources	-	All the validation and sales equipment of the NS
Ticket machines	-	Different models ET2006, ET2000 and AVM
Travellers nuisance	-	When the traveller is inconvenienced because the station resources no longer meet the requirements of the traveller
Qualifier	-	Employee of Thales who prepares the incomplete or unclear incidents for scheduling

Abbreviations

ATM	-	Automated Teller Machine
AVM	-	Add Value Machine
BSM	-	Manage Stations Resources ("Beheer Stations Middelen")
BTS	-	The access control gates
CBM	-	Condition Based Maintenance
CMDB	-	Configuration Management Data Base
CI	-	Configuration Item
CiCo	-	Check in Check out pole, NS card reader
KPI	-	Key Performance Indicator
KVA	-	Ticket Vending Machine ("Kaart Verkoop Automaat")
LBS	-	The Desk Systems ("Loket Balie Systemen")
NS	-	The Dutch Railways ("Nederlandse Spoorwegen")
OEE	-	Overall Equipment Effectiveness
OV	-	Public Transport ("Openbaar Vervoer")
OVCP	-	Public Transport Chipcard and Gates ("OV-Chipkaart en Poortjes")
PA	-	Principal Agent
RCM	-	Reliability-Centred Maintenance
PdM	-	Predictive Maintenance
PM	-	Preventive Maintenance
PTO	-	Public Transport Organization
SA	-	Service and Alarm column
SLA	-	Service Level Agreement
TIP	-	Technical Institutional Process
TODI	-	Technical Maintenance Decentral Infrastructure ("Technisch Onderhoud Decentrale Infrastrutuur")
TPM	-	Total Productive Maintenance
TTS	-	Thales Transportation Systems
TQEI	-	Total Quality Through Employee Involvement
WOT	-	Work Order Task

Resources of the scope

From left to right: KVA (NS Stations, KVA), LBS (van Woerkom, 2015), Gates (NS Stations), CiCos (Dronkert) and SA (NS, 2018)

1. Introduction

In the first chapter of this thesis, the conducted research will be introduced starting with the problem description. Next the research objective will be set out in the second subchapter. A set of research questions will be formulated in Subchapter 3, which will help to fulfil the objective. In the fourth subchapter the scope of the research will be described and in subchapter five the method is presented how the answer to the research question will be found.

1.1. Problem description

Developments in technology lead to many changes. The same goes for the development of electronic card systems in different areas. Card payment systems nowadays enable people to pay by card, to check in at the airport with mobile phones and no physical ticket is required for access to an amusement park. The use of electronic registration systems went hand in hand with the introduction of all these card systems.

In the Netherlands another example of an electronic card system is the OV chip card in the Netherlands. Due to the introduction of the OV chip card in 2005 at the subway in Rotterdam and its further roll-out the entire urban and regional transport in the Netherlands in 2011 (van der Zwan, 2011), the layout of stations had to change. When using the OV chip card as a valid ticket, every journey must be registered electronically. To make this feasible, card readers are located as access control ports (Figure 1) and check in and out poles (Figure 2) on all train and subway stations and modes of transport, such as bus and tram, in the Netherlands. The introduction of these systems is increasing and can be recognised in solutions around the globe, such as in the London subway and public transport throughout China. Registration systems implementation however, differ in each country.

Figure 1, NS Access Control Port (Jacobs, 2016)

Figure 2, NS Check in-Check out pole (Doslu, 2016)

Electrical card and registration systems, like the OV chipcard, offer many advantages but there are also disadvantages. From a traveller's point of view, any kind of delay needs to be avoided. Trains run at a precise time schedule. Any extra step in the passenger's trip – caused by station resources - may therefore not take extra time. The average availability of the station resources is at least 99%. This percentage is high, but still there are on average 300 (NS, BSM) disturbances to the station resources of the Dutch Railways (NS) per week, which affect the traveller's comfort in a negative way. Any disturbance should be placed in a context in order to validate the impact for the traveller. In some cases the impact can be huge and in other cases a disturbance may not influence travellers comfort at all. The 99% availability can therefore give a distorted picture.

The station resources from the NS, which are necessary for the use of the OV chip card, include the Desk Systems, the NS ticket machines, the NS card readers (CiCo), the Service and Alarm column (SA) and the access control gates (BTS) (NS, Dienstencatalogus Stationsmiddelen 2017, 2018). The NS owns these resources and has an external contractor (Thales) made responsible for the maintenance.

Maintenance has become more complex over time due to the fact that a wide variety of different resources need to be maintained. There is an important rule between NS and Thales is related to the service level: if a failure of the station resources is reported and the functionality of the resource is down, this must be resolved within 4 hours.

In this process flow, inefficiencies are observed 1) by the cooperation, 2) by the maintenance process and 3) by the maintenance strategy that is applied. In the cooperation between the NS and Thales inefficiencies occur due to the lack of knowledge about each other's systems and processes. Also, inefficiencies occur due to the misalignment of maintenance strategies on station resources. At the moment, periodic- and reactive action is being taken in the area of the repair of station resources. Reactive maintenance, also often referred as breakdown maintenance or corrective maintenance, is very much a reactive strategy where repairs are performed at the point when equipment fails. The disadvantage of this maintenance strategy is that it is a far more costly approach for an organisation in comparison to proactive maintenance due to unplanned production downtime, damaged machinery, overtime and costs (Hansford Sensors, 2018).

That is why it is interesting to explore the advantages of other maintenance strategies, which is also taken into account in the vision of both companies. The vision of the NS and Thales for the future is to change the maintenance process from a reactive to a proactive and preferably preventive way in order to limit the inconvenience for the traveller. If there is the possibility of preventing failures by introducing maintenance on time, this saves time and, therefore also, traveller inconvenience (Lenahan, 2006).

This new maintenance approach is made possible by the use of sensors and the Internet of Things (IoT) for the station resources. Internet of Things is fast emerging and becoming an almost basic necessity in everyday life. The concept of using technology in daily life is not new, but with the advancements in technology, the impact of technology in the daily activities of a person can be seen in almost all aspects of life (Dhall & Solanki, 2017). With the help of the sensors and the IoT, big data can be collected and smart data can be made of it. As a result, preventive maintenance is possible and so it becomes a real alternative as a maintenance strategy for station resources for the future. Besides preventive maintenance, there always will be incidental failures, so reactive maintenance will remain. The goal is to significantly reduce the number of incidental failures, by having more planned maintenance, resulting in less inconvenience for the traveller.

The research will have a practical and scientific contribution. The NS Thales case brings a good opportunity to gain new empirical knowledge about maintenance strategies for these types of registration systems. Secondly, it also provides an additional scientific contribution because the research is not only based on purely technical and economic improvements theories, but also on cooperation-, assignment- and contracting issues arising from the principal-agent theory (Braun & Guston, 2003). NS and Thales are in a typical principal agent relation in this case. This will be further explained in Chapter 2.1. The principal-agent theory might influence the economic maintenance theory. However, little is known into which extend this influence exists. This research will combine the theory of efficient maintenance with the principal-agent theory, which is a new terrain. When searching for keywords such as "efficient", "waste", "maintenance", "electronic registration systems", "smartcard", "station resources", "public transport", "railway station", "reactive maintenance", "proactive maintenance", "preventive maintenance", "principal-agent" "cooperation" in search engines as Google Scholar, Scopus and the repository of the TU Delft, little useful information could be found.

1.2. Research Objective

Due to the new technologies that have been required since the introduction of the OV chip card, travellers have now become dependent on machines. As shown by the numbers in the introduction, a lot of station resource failures have arisen since the use of electronic registration systems which can have a negative impact on passengers. This research will examine whether improved cooperation between companies and a different maintenance strategy can lead to a solution that will minimize this negative impact for travellers.

Previous research has been done on various maintenance strategies and the use of IoT in other cases such as with connected cars (see Appendix 3). However, little research has been done into the maintenance process of the electronic card systems sector of public transport companies, taking into account not only the economic and technical side but also the 'softer' side such as cooperation and trust. That is why this research will look at how maintenance can be organised in a better way by an in-depth case at the NS and Thales. In Chapter 2, the literature gap is further explained.

Adjustments to the current system should not be at the expense of the traveller, even if solutions are more advantageous for the NS or Thales. The availability of the equipment must remain at least at the same level (also cost wise).

The outcome of this research will provide a scientific contribution for comparable systems such as electronic registration systems for other train, bus, tram and subway operators in the Netherlands since they all work with the OV card. In other countries, electronic registration systems are also being increasingly used. Examples include Sydney's Opal Card, London's Oyster card, South Korea's T-money, Hong Kong's Octopus card, Stockholm's Access card, Japan's Suica and Pasmo cards, Manila's Beep cards, Nigeria's ETC Card, Paris' Calypso / Navigo, Toronto's Presto card and Lisbon's LisboaViva card (Wikipedia, 2018). The outcome of this research might be useful for making the maintenance process more efficient for all these systems. Systems in a field other than Public Transport, such as ATMs on the street, are also similar to the station resources and can, therefore, benefit from this research.

1.3. Research Question

The research objective results in the main research question to fill the knowledge gap about the maintenance part of the resources of logistic companies. The proposed research question is:

How can the maintenance process of the station resources of the NS and Thales be improved without negatively impacting travellers' experience?

The research question will be answered with the use of the following sub-questions:

1. *Which maintenance strategies can be addressed, what are the pros and cons?*
2. *Does the function, history and goals of the companies affect the efficiency?*
3. *What is the process flow of the current system?*
4. *What are the inefficiencies of the current system?*
5. *What are the requirements for the maintenance of station resources?*

These questions are a guidance through the thesis in finding out how and why processes are currently managed and which inefficiencies have a negative impact on the system. It covers the entire maintenance process of the station resources, so the collaboration between NS and Thales will be part of the investigation. By answering the five sub-questions, a solution on how to better organise the maintenance process, should be found.

1.4. The scope of the research

Within the scope of this research are the station resources of the NS where Thales is the party that solves the failure. This automatically involves a mechanic at Thales.

A list of these resources is below:

- The Desk Systems (LBS)
- The NS ticket machines (ET2006/ET2006+/AVM)
- The NS card readers (CiCo)
- The Service, Alarm and Info column (SA)
- The access control gates (BTS)

Disruptions that the NS itself can solve, for example by resetting the gate or pale from a distance, do not fall within the scope.

1.5. Methodology

To answer the research question and related sub-questions as stated in paragraph 1.3, an approach and research methodologies should be selected. Chapter 2 will describe theory to highlight that inefficiencies and improvements do not only relate to purely economic and technical perspectives but also may partly be caused by principal-agent aspects like trust and contracts. This will be taken into account during the research. In addition to the quantitative information analysis, by data analysis in Chapter 3.3, also the softer information side addressing the cooperation between the NS and Thales will be investigated through interviews and observations.

Koppenjan and Groenewegen (2005) provide an approach that can be used as a basis for the research framework. Their technical institutional process design (TIP) considers the design of a complex technological system, which exists of a combination of technological, institutional and process designs. The design of a more efficient maintenance strategy for the NS and Thales could be based on the same design principles; the technological design of this research consists of the technical devices, services and environments. The institutional design includes the responsibilities of the different actors and the process design contains the implementation plan for solving the inefficiencies in the current process.

Koppenjan & Groenewegen (2005) propose the model of design by Herder & Stikkelman (2004) as a straightforward description of the design steps to be taken for a TIP design. This approach is used to base the research framework for this research on, as can be seen in Figure 3.

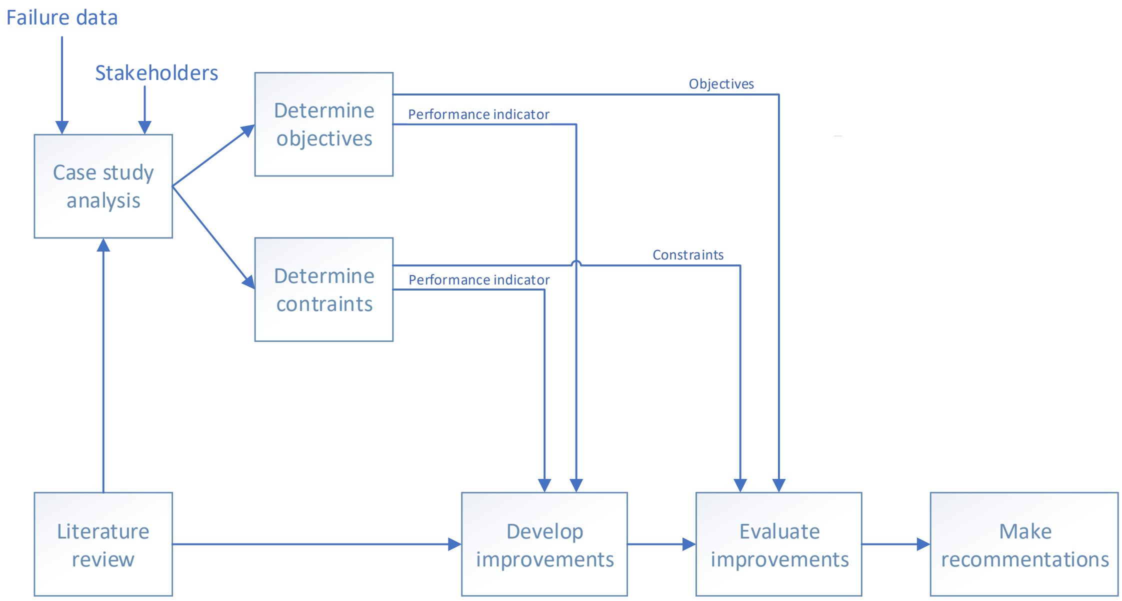

Figure 3, Methodological framework for this research, based on the metamodel of design (Herder & Stikkelman, 2004)

In this framework, the different steps of this project are presented. In the next paragraphs, the different steps will be discussed and the used methods will be briefly explained.

1.5.1. Literature review

For the first step of this research, a literature review is done to explore theories. The research explores different maintenance strategies, the theory behind the economic approach of maintenance and different topics about (in)efficiencies in maintenance. This reflects the preferred theory, see Chapter 2.2, 2.3 and 2.4 and helps to provide a starting point in terms of knowledge and insights of the research field in which the maintenance of the station resources is located.

A lot of research has been done on maintenance strategies for equipment in factories, but in this case the party that maintains the resources is a different party than the one who gives the order. That is why it is also useful to look from the principal-agent theory to this case study because it provides knowledge about potential problems and solutions in the cooperation between principals and agents, see Chapter 2.1.

The results of this review are presented in Chapter 2 and research sub-question 1 can be answered. Lastly, in Appendix 3 analogue maintenance studies are addressed, to seek for potential differences and to avoid reinventing the wheel.

The collected knowledge from the literature on these various topics can then be used in the analysis of the current maintenance process of the NS and Thales (the case study) and in the design process of the improvements.

1.5.2. Case study analysis

As the next step in this research, an analysis of the maintenance process was executed. Now that the theory is discussed in Chapter 2, it helps to explain why and which inefficiencies occur through the principal-agent collaboration. The maintenance process of NS and Thales can be considered as a case study. A case study research allows the exploration and understanding of complex issues. It can be considered a robust research method particularly when a holistic, in-depth investigation is required (Zainal , 2007). A case study is used to research a small domain in depth by selective and intensive data generation on site, often making use of qualitative research methods as (group) interviews and observations. An advantage of a case study is the possibility to obtain an overall picture of the research object. Other advantages are the flexibility of a case study and the less distant role of the researcher to people in the field, which makes the results of the study more acceptable for those stakeholders. A possible disadvantage of the case study is the external validity of the results. Since mostly only one case is studied, it is difficult to apply results to a broader population (Verschuren & Doorewaard, 1998).

For this research, a case study was done at the NS and Thales about the maintenance of the station resources. To understand how the system of this case study works, it was first essential to see who the main actors are, with their associated objectives and constraints. Subsequently, the current situation of this case study has been mapped out in two ways. Firstly qualitative research was done through interviews, document analysis, such as the contracts, and observations within the system. Using this method, a view of the process can be formed in an objective manner. Because at the start of the research, the NS and Thales barely know what processes are taking place in the whole process, so this must be found out on the basis of the qualitative analysis, so that ultimately the inefficiencies in this process can be mapped.

Interviews were held with experts at both the NS and Thales, people from the management team, but also executive people such as an operational manager of the Operation Centre at the NS or the application manager at Thales. In addition, a working day in the life of a Thales mechanic is observed, and there is looked at the work the Thales planner and qualifier entailed and what they have to deal with during a typical workday. There is also looked at the NS Operation Centre to see how the incident process is proceeding there. An overview of all interviews and observation moments can be seen in Table 1.

Table 1, Overview of interviewed and observed people from the NS and Thales

	No.	Function	How*
NS	1	Manager of Station Resources, Thesis supervisor	Interviews, bilateral meetings, MT meetings, informal meetings, telephone contact
	2	Team Leader Software support	Interview, MT meetings
	3	Manager Station layout	Interview, MT meetings
	4	Team Leader Analyse	Interview, MT meetings, informal meetings
	5	Team leader Product management	Interview, MT meetings
	6	Team leader Operations Centre	Interview, MT meetings
	7	Information Analyst Station resources	Interviews, informal meetings
	8	IT Manager, Process & Chain Optimization	Interview
	9	Functional Application Manager	Interview
	10	Product manager i.e.	Interview, informal meetings
	11	Product Manager	Interview
	12	Operational Manager	Interviews, telephone contact, informal meetings
	13	Product manager	Interview, informal meeting
	14	Contract	Interviews, informal meetings
	15	Operational Manager	Observations by watching the Operation Centre process for a few hours, informal meetings
	16	Product manager	Interview, informal meeting
	17	Incident management	Informal contact
Thales	18	Director Customer Service, Thesis supervisor	Interviews, bilateral meetings, informal meetings, telephone contact
	19	Process manager	Interview, informal contact
	20	Team manager Logistics	Interview
	21	Team leader and assisting foreman planning	Interview
	22	Consultant, Thesis supervisor	Interviews
	23	Program Director E-ticketing and Director Supply chain	Interviews
	24	Senior Service Mechanic	Telephone contact and watch during a workday
	25	Planner	Observations by watching the planning process for a few hours
	26	Application management	Data collecting
	27	Service Desk employee - qualifier	Observations by watching the qualifier process for a few hours

* An interview is a moment when an appointment is made for an interview, duration was usually one hour. Informal contact is quick contact for short questions, tips and or comments.

First, interviews were held with the team managers and specialists, *No. 1, 2, 3, 4, 5, 6, 8, 10, 11, 13, 14, 16, 17* from the NS and *No. 18, 19, 20, 21, 22, 23* from Thales in Table 1 to get an idea of the general process and what each company does and how it works. After that, interviews with the executive people *No. 7, 9, 12, 15* from the NS and *No. 24, 25, 26, 27* from Thales in Table 1 were held to get an insight into the actual process of the maintenance. Because managers and specialists can have a certain picture of the process, but in practice it can work differently. That is why also interviews were held with the people who actually carry out the process.

The most important questions that were asked during an interview were about understanding someone's function within the company, his contribution to the current maintenance process and gaining insight into the current process by asking why things happen the way they do. In addition, the principal-agent theory in Chapter 2.1 has learned that trust issues and power imbalances can occur in a collaboration. That is why there is asked whether this also takes place within this collaboration between the NS and Thales and, if so, how that results in inefficiencies. The literature on the advantages and disadvantages of certain maintenance strategies and waste types was also included in the interviews, to find out if and where other inefficiencies occur in the process and how these inefficiencies could be solved. That was especially important for the solutions that will eventually be presented in Chapter 5.2. It was striking that the executives often thought in limitations because some inefficiencies cannot be solved within current systems such as the databases and Service Now. The team managers saw far fewer restrictions.

The summary and conclusions drawn from each interview and observation have been fed back to the relevant people to check whether there were any misconceptions. After approval, the information was used as input for the research. In addition to the interviews, informal contact has also taken place for short questions that were encountered. The NS and Thales use a lot of abbreviations and expressions, so there was sometimes asked for clarification or some explanation of how certain data should be interpreted.

In addition, if the NS said something about Thales, that was fact-checked at Thales and vice versa, so an objective investigation was conducted. Because it became clear during interviews that there is a lot of annoyance and ignorance about each other's work and processes, so not all the information provided about each other was objective and correct.

Through these analyses, the current process of maintaining the stations (Chapter 3.2) could be mapped. Secondly, quantitative research was used in the case study to perform a data analysis on all failures, see Chapter 3.3. The incident data from the NS and Thales were compared and conclusions were drawn. As a result, findings could be shared on the number of periodic and reactive maintenance, the type of failures, the resolution time and repeated failures. The inefficiencies arising from each research method are listed at the end of each subchapter.

In addition to the process becoming clear through the interviews and observations, the requirements of the NS and Thales also became clear. To map the requirements of the third main actor, the traveller, five travellers were interviewed, see Table 2.

Table 2, Overview of interviewed travellers

	No	Who	Function	How
Traveller	28	Traveller (m) of 23 years	Study trip	Interview
	29	Traveller (m) of 27 years	Study trip	Interview
	30	Traveller (m) of 57 years	Work trip	Interview
	31	Traveller (f) of 53 years	Leisure trip	Interview
	32	Traveller (f) of 83 years	Leisure trip	Interview

These people were interviewed because surveys about passenger satisfaction of the NS do not ask specifically for the station resources part. In order to get some impression, very exploratory research was done by interviewing these 5 people about what they think are important requirements of the station resources. This has no scientific value, but it gives a rough idea of the real situation. An attempt was made to combine the diversity within the passenger profile of the NS by questioning people from different ages, gender and trip purposes.

On the basis of interviews and the data from Chapter 3.1, 3.2, and 3.3, the requirements of the system for the station resources could be mapped in Chapter 4. As a result, sub-questions 2, 3, 4 and 5 are answered in Chapter 3 and 4.

1.5.3. Develop efficient improvements

With the knowledge from the literature study, the determined inefficiencies and the experience gained during the analysis of the case study from interviews and field observations, Chapter 5.1 establishes an improved maintenance situation. From this, proposals were made for designs to improve the current situation towards the improved situation. This was done by looking at the inefficiencies that emerged from Chapter 3.1, 3.2 and 3.3 and confronting these inefficiencies with the requirements from Chapter 4. The inefficiencies ensure that the requirements of the main actors cannot be met, so that the current maintenance situation is suboptimal. Therefore, using the knowledge gathered from qualitative research, solutions have been designed for inefficiencies. This means that the requirements of the main actors and therefore the requirements of the design of the preferred maintenance for the station resources can still be (partly) achieved.

Various improvements were then tested for feasibility by interviews with the executive people. An example of this in Chapter 5.2, is the proposal to remove a physical booklet containing notes about repairs. Both the mechanic at Thales, the people at the NS Operation Centre and product managers at the NS were checked (*No. 11, 12, 13, 15* and *24* from Table 1) to see if this was actually possible.

1.5.4. Evaluate efficient improvements

The improvements formulated in the previous step, are evaluated in Chapter 6 through discussions with experts from NS and Thales, *No. 1, 22* and *23* from Table 1. These three experts were chosen because they have a good overview of the entire organisation of both companies and their leadership principles are not to be bound by limitations, but to be open for new insights. This makes the discussion interesting because improvements might not be possible on short notice, but they will be for the future. Interviews revealed that executive people are focused on their own part of the process and are often limited in finding solutions because they immediately see the limitations and could not see the broader picture of the process. For example, the limitation of the systems they are using. Of course, these limitations need to be taken into account, but when looking at the whole process, a more open view is more desirable.

The designs will not be tested as suggested in the Herder & Stikkelman (2004) design. The limited timeframe of the graduation period does not allow to test the improvements. They should have been tested for at least one month, in order to make comparisons with historical data and Key Performance Indicators (KPIs). The evaluation will therefore be qualitative and not quantitative.

In Chapter 6 the designs and the consequences for the different main actors are explored. In addition, a prioritization has been made for the implementation of the solutions. Conclusions are drawn in Chapter 7 resulting in the answers to the pre-defined main- and sub research questions.

1.5.5. Make recommendations

The research will be concluded by presenting a set of recommendations in Chapter 7. The distinction is made in recommendations for further research and recommendations specifically addressed to the case study companies. These recommendations explain how certain solutions still have to be worked out to achieve the desired effect. Because in this research only proposals are made for a more efficient maintenance situation, but the precise interpretation has yet to be determined.

Conclusion

This chapter explained the problem of the research with a corresponding research question. Subchapter 1.5 then explains how the answer to the main question will be found with the help of a methodological framework based on the design of Herder & Stikkelman (2004).

Table 3 provides an overview of the report structure, the discussed topics per chapter and when which sub-question is answered.

Table 3, Report structure and summary of the content

Chapter	Discussed topics	Answers sub-questions
1. Introduction	Background, problem definition, research question, methodological framework and report structure	
2. Theory	Principal-agent theory, economic relevance of maintenance, maintenance strategy studies, different topics about (in)efficiencies in maintenance	1
3. Process analysis	Stakeholder analysis, current process analyse, data analysis	2, 3, 4
4. Requirements	Requirements of the main actors	5
5. Design	Formulation of a preferred maintenance situation and solutions to reach this situation	
6. Evaluation	Comparison current maintenance process and future scenarios	
7. Conclusion and recommendations	Research question, reflection on improvements, limitations and future research	

2. Theory

In this research, it is assumed that efficient (or improved maintenance strategies) will not only depend on economic maintenance theory, Chapter 2.2 and 2.3, but also on principal-agent theory, see Figure 4. Because in the case of cooperation between different parties there may be a common main objective, but each party always has its own interests to which it acts, see Chapter 2.1. It is therefore deemed important that this theory is also included in the research because it looks at how issues such as trust and power imbalances can be resolved and not only focusing on how knowledge from literature about economic relevance, maintenance strategies and quantitative data research will result in improved maintenance.

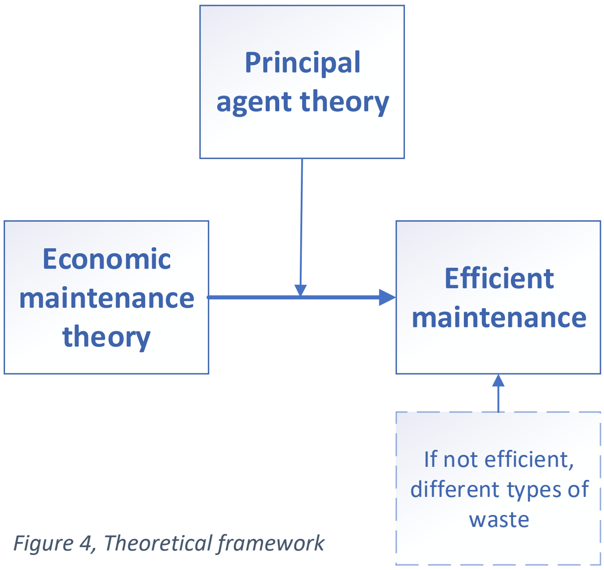

Figure 4, Theoretical framework

The concept of (in)efficiency in processes is explained in Chapter 2.4. In addition, a classification is made of the type of waste, in which any inefficiencies that arise from the principal-agent theory or the incorrect implementation of the maintenance theory, can be classified. The literature on this subject helps to create structure during the further analysis in the research and the drafting of the solutions in Chapter 5.

2.1. Principal-agent theory

Of course, all companies want to be efficient, but inefficiencies often occur when companies work together. In this Subchapter, one of the theories on which this research is based will be explained, namely the principal-agent theory. This theory explains the possible inefficiencies in the maintenance process of the station resources due to different interests.

The principal-agent literature deals with a specific social relationship, that is, delegation, in which two actors are involved in an exchange of resources. The principal is the actor who disposes a number of resources but when he is not those of the appropriate kind to realise the interests, there is an agent needed (Braun & Guston, 2003). The agent accepts these appropriate resources and is willing to further the interests of the principal. Between these two parties, there is usually a hierarchical structure.

There are two typical collective action problems because of the principal-agent structure discussed in the literature; moral hazard and adverse selection. These problems are based on what the new institutional economics (Moe, 1984) calls the 'opportunism' of actors. Actors are self-interested and thus seek to maximise their own welfare. The principal does not know for sure if the agent will really do its best when delegated certain tasks, this is the *"moral hazard"*, and usually the principal does not have sufficient information on the abilities of potential agents to find the one best suited to do the task, this is *"adverse selection"* (Braun & Guston, 2003).

The collective action problems arise as both sides — the principal and the agent — have an interest in entering into the exchange relationship. They both profit by exchanging resources: the principal by getting something done he or she could not otherwise do, and the agent because he or she gets remuneration of some kind (money, social recognition, and so on). Despite these mutual advantages, the collective outcome may be suboptimal because, as is said, the agent has incentives to seek his self-interest with guile. However, also the possibility of the principal to 'shirk' should not be forgotten. This subject is often not discussed in the literature. He or she may have incentives not to deliver the resources fully as agreed to in the contract. Because of these co-operative and selfish motives characterising the relationship, principal-agent interaction is a ‘mixed-motive game’ (Braun & Guston, 2003).

The two aforementioned collective action problems are primarily caused by three things; First of all, full cooperation is often limited by the heavy *power imbalances* between partners. By maximising their own profits, powerful companies mostly prevent other parties from getting benefits or may even force them into loss (Hingley, Lindgreen, & Casswell, 2006).

The second and most important cause as mentioned by multiple studies is *trust.* Companies are afraid that their willingness to cooperate will be misused by their partner. This is also mentioned by Zhao et al.: "Many companies are reluctant to share information with their trading partners, afraid that the information will be used unfairly to their disadvantage" (Xiande Zhao, 2002). It is difficult to say if partners optimize their own processes only instead of working towards an optimum (Parkhe, 1993). This is reinforced by the fact that the chain optimum is not equal to the summed optimal of each partner (Northcraft, 2007).

Lastly, *the willingness of partners to change behaviour* in favour of the other party can be an issue as well. Therefore, even with full sharing of information, it does not automatically mean that the information is used by partners to increase revenues besides their own (Pereira, 2009).

The relationship between the NS and Thales in the maintenance of the station resources can be described as a principal-agent relationship. The station resources are owned by the NS (principal), but the NS hires Thales (agent) to carry out the maintenance. They have a common interest, namely that travellers can use the station resources in the best way possible, but both parties also have their own interests, see Chapter 4, which do not always join together. From this, it can be concluded that during the interviews and observations for the research there must be looked at how the interests of both parties differ and where and as a result of which the collaboration is not going well. So that power imbalances, trust issues and not willing to change behaviour for the partner are better understood and it can be taken into account when formulating the improvements in Chapter 5.

2.2. The economic relevance of maintenance

When looking at maintenance and the way it is carried out, costs play an important role. It is therefore interesting to conduct literature research on this topic, because when servicing station resources it is essential that the costs are always lower than the benefits so that a company can make a profit. When looking at investments in new equipment versus the maintenance of existing equipment, there are two extreme scenarios, see Figure 5. At the firsts extreme (1) it can be an advantage to use existing equipment for as long as possible. The investment costs in new equipment are low, but the result of this strategy is that parts are increasingly broken and a lot of maintenance is needed to repair the equipment again. The maintenance costs are therefore high at this extreme and besides, disturbances cause inconvenience to users, which can also be expressed in costs (not included in Figure 5). The opposite is extreme (2), investing in new equipment every year. This can be advantageous because it will rarely break down and the maintenance costs will be low, but the investment costs will then be enormous. There is an optimum between the two.

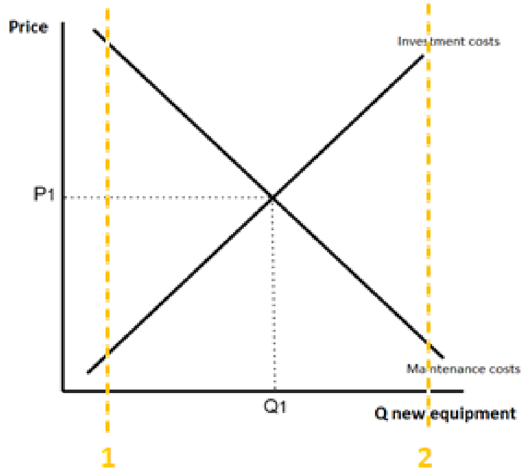

Figure 5, The maintenance-investment relationship

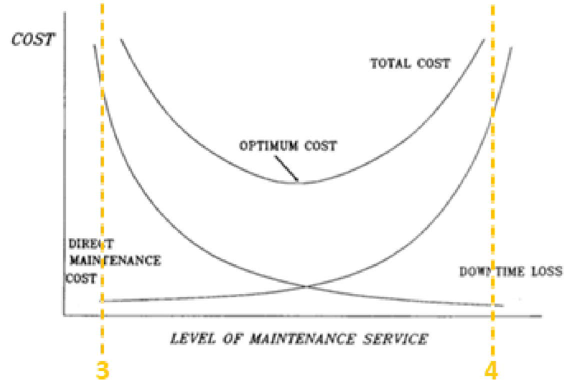

Figure 6, The maintenance type-cost relationship (Woodward, 1997)

In addition, there is an inverse relationship between the costs and the maintenance strategy, see Figure 6. A reactive approach reduces maintenance expenditures but increases downtime loss (3). A regular, planned, preventive maintenance policy, on the other hand, reduces the downtime costs but resources are used in the form of maintenance expenditure (4). It is essential that a regular planned maintenance policy is maintained for those items of equipment that incur high downtime costs whereas items of equipment incurring low downtime costs can be attended to or replaced as they wear out. The key factor is to find an optimal level of maintenance service in order to be consistent with the organisation's objective of attaining minimum total cost (Woodward, 1997).

Therefore it can be concluded that the economic aspect of maintenance must be taken into account during the interviews, observations and in the quantitative data analysis. Because the NS and Thales are both commercial companies that have to earn money.

At this moment, the maintenance strategy and process inefficiencies cost money, but it is interesting to see how much money is available to solve these inefficiencies. As mentioned above at the first extreme, the NS will not install new equipment every year, even though this means that there will be fewer disruptions. In addition, Thales also will not deploy too many mechanics so that the disruptions will be resolved faster, because this costs far too much money and there is no balance with what it yields.

2.3. Maintenance Strategies

In the past, maintenance problems received little attention and researches in this area did not have much impact. Today, this fact is changing because of the increasing importance of the role of maintenance in the new industrial environment. Maintenance, if optimised, can be used as a key factor in organisation’s efficiency and effectiveness. It also enhances the organisation’s ability to be competitive and to meet its stated objectives (Ben-Daya, Duffuaa, & Raouf, 2000).

In addition, effective maintenance is more and more critical to many operations. It extends equipment life, improves equipment availability and retains equipment in proper condition. Conversely, poorly maintained equipment may lead to more frequent equipment failures, poor utilisation of equipment and delayed production schedules. Misaligned or malfunctioning equipment may result in scrap or products of questionable quality. Finally, poor maintenance may mean more frequent equipment replacement because of shorter life spans (Swanson, 2001).

Maintenance actions can be classified in two main categories; the first one is maintenance, in which actions are done before the equipment or machine is broken to prevent any kind of failure; and the second one is repair, which is done after a failure occurs to restore the machine to the working condition. Actually maintenance and repair are two supplementary functions, but the primary function is maintenance. The inevitable failures which occurred despite the maintenance are fixed with repair. Failures can be seen in every machine but the aim is to minimise these failures (Swanson, 2001).

Many authors have described different strategies for maintenance management, see Figure 7. In general, maintenance techniques can be divided into three branches. In the first branch, maintenance only takes place if the system has stopped working and has called reactive maintenance. In the second branch, proactive maintenance tries to foresee upcoming problems in the system to prevent total failure. Preventive, predictive and Reliability-Centred Maintenance represent three proactive strategies by which companies can avoid equipment breakdowns (Bateman, 1995). The third branch includes aggressive maintenance techniques, like Total Productive Maintenance (TPM) (Weil, 1998), which have emerged, since advances in personnel qualification and information systems made them viable. They propose an all-encompassing strategy to achieve better performance while lowering failure rates (Swanson, 2001).

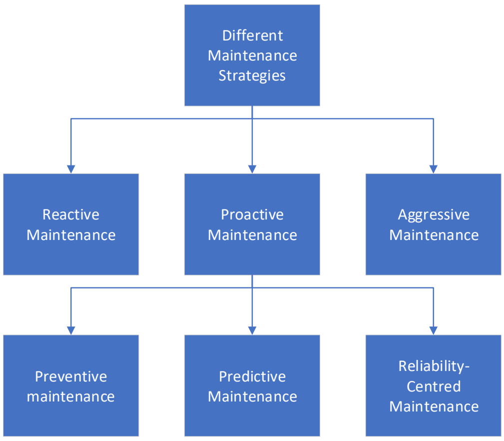

Figure 7, Overview maintenance strategies

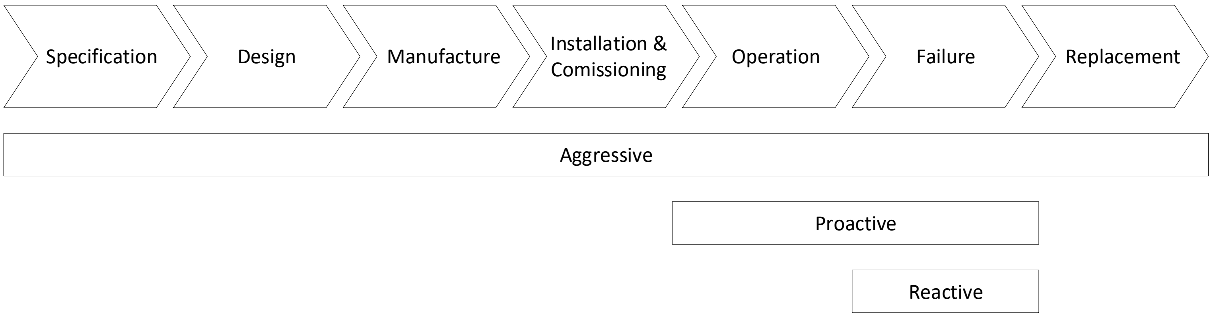

Figure 8, Maintenance techniques and their scope of application along the equipment lifecycle (Kelly, 2006)

Figure 8, depicts the scope of the different maintenance strategies. Aggressive maintenance is a holistic approach, whereas the other two techniques concentrate on only specific parts of the equipment's lifecycle. It is important to note that these techniques are not mutually exclusive. This implies that even if the most sophisticated aggressive strategy is in place, there will still be occasions where the system breaks down and reactive maintenance is needed (Gassner, 2009).

In the remainder of this chapter, the main maintenance strategies will be explained and the advantages and disadvantages will be mapped out.

2.3.1. Reactive Maintenance

Traditionally, many companies deployed a reactive, also known as breakdown, strategy for maintenance, it can be described as a fire-lighting approach to maintenance Equipment is allowed to run until failure. Then the failed equipment is repaired or replaced (Paz & Leigh, 1994). With reactive maintenance, temporary repairs may be made in order to return equipment to operate, with permanent repairs put off until a later time (Gallimore & Penlesky, 1988). Reactive maintenance allows a production plant to minimise the amount of maintenance manpower and money spent to keep equipment running (Vanzile & Otis, 1992). However, the disadvantages of this approach include unpredictable and fluctuating production capacity, higher levels of out-of-tolerance and scrap output, and increased overall maintenance costs to repair catastrophic failures (Bateman, 1995) (Gallimore & Penlesky, 1988).

2.3.2. Proactive Maintenance

Proactive maintenance is a strategy for maintenance whereby breakdowns are avoided through activities that monitor equipment deterioration and undertake minor repairs to restore equipment to proper condition and reduce the probability of unexpected equipment failures (L. Swanson). These tactics include Preventive Maintenance (PM), Predictive Maintenance (PdM) and Reliability-Centred Maintenance (RCM). Preventive Maintenance is based on set maintenance interval, whereas Predictive Maintenance follows a strategy of monitoring, diagnosing and forecasting failures of the deteriorating system. Reliability-Centred Maintenance was initially suggested to enhance aircraft and power plant maintenance but found its way into the goods producing industries (Dekker, 1996). By integrating PM and PdM, RCM puts greater emphasis on maintaining the system's function rather than restoring an ideal condition (Sharma, Kumar, & Kumar, 2005).

Preventive Maintenance

The purpose of preventative maintenance is to prevent assets from breaking down by performing maintenance regularly – instead of conducting maintenance once the failure has occurred. Preventive maintenance is often referred to as use-based maintenance. It is comprised of maintenance activities that are undertaken after a specified period of time or amount of machine use (Gits, 1992) (Herbaty, 1990)**.** This type of maintenance relies on the estimated probability that the equipment will fail in the specified time interval. The work undertaken may include equipment lubrication, parts replacement, cleaning and adjustment. Production equipment may also be inspected for signs of deterioration during preventive maintenance work (Baglee, Maintenance Strategies, 2018).

Predictive Maintenance

Predictive maintenance is often referred to condition-based maintenance (CBM). Specifically, maintenance is initiated in response to a specific equipment condition (Vanzile & Otis, 1992) (Gits, 1992). Under predictive maintenance, diagnostic equipment is used to measure the physical condition of equipment such as temperature, vibration, noise, lubrication and corrosion (Eade, 1997). When one of these indicators reaches a specified level, work is undertaken to restore the equipment to proper condition. This means that equipment is taken out of service only when direct evidence exists that deterioration has taken place.

Predictive maintenance is premised on the same principle as preventive maintenance although it employs a different criterion for determining the need for specific maintenance activities. As with preventive maintenance, predictive maintenance reduces the probability of equipment breakdowns. The additional benefit comes from the need to perform maintenance only when the need is imminent, not after the passage of a specified period of time (Herbaty, 1990) (Nakajima, 1989).

Reliability-Centred Maintenance

Integrating preventive and predictive maintenance, Reliability Centred Maintenance (RCM) follows an approach of prioritising systems' and components' failure modes, according to their importance to system functioning (Dekker, 1996) (Sharma, Kumar, & Kumar, 2005). Moubray (Moubray, 2000) defined RCM as a systematic approach used to optimise preventive and predictive maintenance programs to increase equipment efficiency (uptime, performance and quality) while targeting on minimising the maintenance cost. In RCM methodology the focus is on maintaining system function rather than restoring equipment to an ideal condition. The primary objective of RCM is to preserve system function. To attain this objective, various failure modes that cause functional failure are identified, then prioritised accordingly to reflect their importance in system functioning. Tools such as failure mode and effect analysis (FMEA) and fault tree analysis (FTA) are used in RCM analysis (Sharma, Kumar, & Kumar, 2005).

2.3.3. Total Productive Maintenance

More holistic maintenance concepts constitute aggressive maintenance techniques. The best known of these is Total Productive Maintenance (TPM), which is a Japanese concept for maintenance and includes a companywide approach (Nakajima, 1989). Since there is more to maintenance than just stopping a system for failing, aggressive maintenance techniques simultaneously try to improve the overall equipment efficiency (Ahuja & Khamba, 2008) (Mishra, Anand, & Kodali, 2007).

In TPM the practice of preventive maintenance is combined with the concept of total quality through employee involvement (TQEI) (autonomous maintenance groups). Operators maintain their own machines; they compile and interpret maintenance and operating data of their machines that help to identify signs of deterioration. Routine daily maintenance checks, minor adjustments, lubrication, and minor part changes are the activities performed by the operators (Sharma, Kumar, & Kumar, 2005). While these newer maintenance strategies require greater commitments in terms of training, resources and integration, TPM seeks to improve the overall equipment effectiveness (OEE) and machine performance (Swanson, 2001), which is an important indicator, used to measure TPM. An overall 85% of OEE is considered as world class and a benchmark for others (Blanchard, 1997) (McKone, Schroeder, & Kristy, 1999) (Chand & Shirvani, 2000).

Conclusion

At this moment, preventive but mainly reactive (on average 15% vs 85% in 2018, see Chapter 3.3) maintenance is taking place at the station resources of the NS. Because failures are highly unpredictable, it ensures that the main strategy entails high costs and inefficiencies. This chapter has shown that other maintenance strategies try to limit these disadvantages. However, it is not said that switching to a different maintenance strategy takes away all the disadvantages. Because the other strategies often cost much money because many diagnoses have to be done in advance, the equipment has to be adjusted and mechanics have to be trained differently to be able to carry out the new maintenance strategy.

In addition, as Gassner (2009) has already stated, there will always be occasions where the system breaks down and reactive maintenance is needed, even if the NS and Thales want to switch to a different maintenance strategy. The mechanics can still be maintained so well, something can always break electronically. However, the ratio in which the maintenance strategies are currently being implemented have to change, so that more and more failures are prevented by maintenance and less reactive maintenance is required.

Appendix 2 summarizes all the advantages and disadvantages of each maintenance strategy discussed in Chapter 2.3 and Table 4 provides a clear summary of all these advantages and disadvantages. Hereby, sub-question 1 “*Which maintenance strategies are there, what are the pros and cons?*” of this research is answered.

Table 4, Overview of the different maintenance strategies (Swanson, 2001) (Baglee, Maintenance Strategies, 2018) (Hansford Sensors, 2018)

Strategy	Pros	Cons
Reactive Maintenance	-Minimal planning -Simple process -Less staff required -Ideal for low priority equipment	-Unpredictable -High costs -Possible secondary damage from equipment failure -Inefficient use of staff resources
Preventive Maintenance	-Cost-effective -Periodicity maintenance -Increased component life-cycle -Reduced equipment or process failures	-Catastrophic failures still occur -Labour intensive -Performance of unneeded maintenance -Incidental damage to components through poor maintenance practices
Predictive Maintenance	-Increased component operational life/availability -Allows for pre-emptive corrective actions -Reduced equipment downtime -Decreased costs for parts and labour -Better product quality	-Increased costs due to investment in diagnostic equipment and training of staff -Savings potentials not readily seen by management
Reliability Centred Maintenance	-The most efficient maintenance program -Lower cost by eliminating and minimise unnecessary maintenance or overhauls -Reduced chance of sudden equipment failure -Increased component reliability -Maintenance according to their importance to system functioning	-Very high start-up cost, training, equipment, etc. -Savings potential not readily seen by management
Total Productive Maintenance	-Towards more efficiency in maintenance -Lower cost by eliminating and minimise unnecessary maintenance or overhauls -Reduced chance of sudden equipment failure -Increased component reliability -Companywide approach	-Highest start-up cost, training, equipment, etc. -Savings potential not readily seen by management

For the maintenance of the station resources of the NS it is therefore important that, in addition to the reactive maintenance strategy, another strategy is applied to prevent disruptions. From the strategies in this subchapter, it appears that aggressive (TPM) maintenance is not possible because the scope of maintenance of Thales does not extend that far in the process. According to the contract, Thales is only active in the operation and failure zone and in consultation they also do installation & commissioning and replacement of equipment, see Figure 8. Proactive maintenance, on the other hand, is possible.

From the three ways of proactive maintenance, is preventive the cheapest to implement. However, with this strategy it is difficult to estimate when maintenance is really needed, as a result of which unneeded maintenance is carried out, which costs unnecessary money. This is not the case with predictive maintenance and RCM, because maintenance is determined by estimating and repeatedly checking the life time of equipment components. This is therefore increasingly moving towards the economic optimisation discussed in Chapter 2.2.

Both predictive maintenance and RCM can be applied for the maintenance of the station resources of the NS. However, RCM entails higher start-up costs than predictive maintenance strategy, which does not outweigh the possible benefits of this maintenance strategy, making predictive maintenance the best maintenance strategy for the station resources. Because this strategy is therefore the closest to the economic optimum.

However, this is an implementation for the long-term, because lots of research has to be done before this strategy can be implemented. In the short term, preventive maintenance can take place alongside reactive maintenance, because this implementation requires less research.

2.4. Efficiency in Maintenance

When improving a business, people always talk about improving the efficiency of the system and their employees. However, before it can be determined how an organisation or process can be made more efficient, it is important to know what efficiency is. In Subchapter 2.4.1 the definition of efficiency and in Chapter 2.4.2 the definition of inefficiency from the literature is explained. The inefficiencies are then classified into waste types, which helps to categorise the inefficiencies resulting from the collaboration between NS and Thales and the current maintenance process from Chapter 4, 3.2 and 3.3. If these inefficiencies from the current situation are classified in the waste groups, it is then easier to find solutions, so that the maintenance of station resources can be made more efficient.

2.4.1. What is efficiency

Efficiency is a relationship between ends and means. It signifies a level of performance that describes the highest amount of output compared to the input. To achieve efficiency, it requires reducing the number of unnecessary resources used to produce a given output including personal time and energy. In other words, it is a measurable concept that can be determined using the ratio of useful output to total input. Where the waste of resources such as physical materials, money, energy, and time needs to be minimized to accomplishing the desired efficient output (Banton, 2019). The output often describes a product or service.

In this research, the resources for the input are people, materials, information and other organisational assets such as financial resources and machinery (Visser, Matten, Pohl, & Tolhurst, 2007). The output is the maintenance service for the station resources. In order to make maintenance as efficient as possible, the number of wasted inputs must be reduced. So preferably solve the failure as quickly as possible at the lowest possible cost.

Efficiency is often confused with the concept of effectiveness. Effectiveness is the degree to which objectives are achieved and the extent to which targeted problems are solved. In contrast to efficiency, effectiveness is determined without reference to costs (BusinessDictionary, 2019). Peter Drucker once made the statement "Efficiency is doing things right, while effectiveness is doing the right things". By combining effectiveness and efficiency, a company produces better products faster and with fewer resources (Miksen, 2019).

2.4.2. What are inefficiencies

By definition, the term inefficiency generally refers to an absence of efficiency and the state of not achieving maximum productivity (Oxford Dictionaries, 2019). It means that scarce resources are not being put to their best use. The idea is to eliminate inefficiency, creating a seamless manufacturing process.

For making the maintenance processes of NS and Thales less inefficient and more (cost)efficient, cooperation between the partners is essential and can enable parties to reduce each other's costs and increase efficiency (Stanley E. Fawcett, 2008). At this moment they are a black box for each other. However, research has shown that when cooperating in a chain up to 60% of costs can be saved (Xiande Zhao, 2002). Other studies have shown less promising results with savings between 5% and 35% by Lofti (Zahra Lotfi, 2013) and an average of 2% cost savings in a study made by Cachon (Cachon & Lariviere, 2000). Even though different results came from the studies, it can be concluded that there are opportunities for savings and in general, all studies state that even with basic cooperation as simple forecast sharing supply chains could become more efficient. Not only creating financial benefits by reducing costs but also by increasing availability and reliability.

This research will not talk about actual amounts of money that can be saved, but from the literature it can be concluded that if the maintenance process from the station resources of the NS is more efficient, this will ultimately yield money for both the NS and Thales.

Type of inefficiencies

Another word for inefficiencies is *waste of resources*. There are many classifications of waste, and one of the most basic and widely used is the Seven Wastes by Taiichi Ohno (Ohno, 1988). These seven wastes are: transportation, inventory, motion, waiting, overproduction, over-processing and defects. This list has been modified and expanded with two more waste types: correction and knowledge disconnection (Mekong Capital, 2004).

Below, the nine types of waste will be explained according to the paper of Khalil A. El-Namrouty and Mohammed S. AbuShaaban (El-Namrouty & Abushaaban, 2013):

- **Transportation:** It includes any movement of materials that do not add any value to the product, such as moving materials between workstations. Transportation between processing stages results in prolonging production cycle times, the inefficient use of labour and space (Mekong Capital, 2004). Any movement in the firms could be viewed as waste. Double handling and excessive movements are likely to cause damage and deterioration with the distance of communication between processes (Hines & Rich, 1997).
- **Inventory:** Inventory waste means having unnecessarily high levels of raw materials, work-in-progress and finished products. Extra inventory requires handling, space and leads to higher inventory financing costs, higher storage costs and higher defect rates (Mekong Capital, 2004).
- **Motion:** It includes any unnecessary physical motions or walking by workers who divert them from actual processing work. This might include walking around the factory floor to look for a tool, or even unnecessary or difficult physical movements, due to poorly designed ergonomics, which slow down the workers (Mekong Capital, 2004).
- **Waiting:** It is idle time for workers or machines due to bottlenecks or inefficient production flow on the factory floor. It includes small delays between processing units (Mekong Capital, 2004). When time is being used ineffectively, then the waste of waiting occurs. This waste occurs whenever goods are not moving or being worked on. This waste affects both goods and workers, each spending time waiting (Hines & Rich, 1997). This can also be caused due to poor planning.
- **Overproduction:** Over-production is unnecessarily producing more than demanded or producing it too early before it is needed. This increases the risk of obsolescence, increases the risk of producing the wrong thing (Mekong Capital, 2004). It tends to lead to excessive lead and storage times. Also, it leads to excessive work-in-process stocks which result in the physical dislocation of operations with consequent poorer communication (Hines & Rich, 1997).
- **Over-processing:** It is unintentionally doing more processing work than the customer requires in terms of product quality or features such as polishing or applying to finish in some areas of the product that will not be seen by the customer (Mekong Capital, 2004). Over-processing occurs in situations where overly complicated solutions are found in simple procedures. The over-complexity discourages ownership and encourages employees to overproduce to recover the large investment in the complex machines (Hines & Rich, 1997).
- **Defects:** In addition to physical defects which directly add to the costs of goods sold, this may include errors in paperwork, provision of incorrect information about the product, late delivery, production to incorrect specifications, use of too much raw materials or generation of unnecessary scrap (Mekong Capital, 2004).

- **Correction:** Correction, or reprocessing, is when something has to be re-done because it was not done the first time correctly. This not only results in inefficient use of labour and equipment but the act of re-processing often causes disruptions to the smooth flow of production and therefore generates bottlenecks and stoppages. Also, issues associated with reworking typically consume a significant amount of management time and therefore add to factory overhead costs (Mekong Capital, 2004).
- **Knowledge Disconnection:** This is when information or knowledge is not available where or when it is needed. This might include information on correct procedures, specifications, ways to solve problems, etc. Lack of correct information often leads to defects and bottlenecks. For example, unavailability of a mixing formula may potentially suspend the entire process or create defective items due to time-consuming trial-and-error tests (Mekong Capital, 2004).

Chapter Conclusion

This chapter shows that maintenance is economically relevant if the costs do not exceed the benefits, so a positive cost-benefit ratio should be achieved. Furthermore, the key factor in finding an optimal level of maintenance service is to be consistent with the organisation's objective or attaining minimum total cost (Woodward, 1997).

The maintenance strategy for the station resources with the best cost benefit ratio is predictive maintenance, and preventive maintenance also comes closer to the economic optimum compared to reactive maintenance. This is because with periodic maintenance, unlike reactive maintenance, failures are prevented and maintenance can take place at any desired moment. This reduces inconvenience for the travellers. Besides periodic maintenance, reactive maintenance, with its disadvantages, continues to exist. There will always be occasions where the system breaks down unexpectedly. But the current ratio between periodic and reactive maintenance 1 to 6 (see Chapter 3.3) will be reversed when the other maintenance strategy is applied. So that the benefits of periodic maintenance prevail.

When optimization of maintenance processes are considered it is necessary not only to look at how the process can improve the economic relevance, like the right maintenance strategy, but also look at inefficiencies which occur by the principal-agent cooperation. The principal-agent theory explains that actors are self-interested and thus seek to maximise their own welfare. The principal does not know for sure if the agent will really do its best when delegated certain tasks, this is the “moral hazard”, and usually the principal does not have sufficient information on the abilities of potential agents to find the one best suited to do the task, this is “adverse selection” (Braun & Guston, 2003). This is a regular issue due to power imbalances, trust issues and the lack of willingness of partners to change behaviour in favour of the other party (Hingley, Lindgreen, & Casswell, 2006), (Xiande Zhao, 2002), (Pereira, 2009).

This chapter has shown that it is important not only to look at *what* causes inefficiencies during the interviews and observations, but also to see *why* they arise. This will often is related to trust issues and power imbalances between the NS and Thales from the principal-agent theory. It is therefore essential to know why inefficiencies occur, so better solutions can be found in Chapter 5 for a more efficient way of maintaining station resources.

Despite the fact that NS and Thales currently operate as a black box they have indicated that they want to play open cards for this research to jointly explore inefficiencies. Given their different interests, it will remain difficult to fully optimise the process for both parties. Because, both the NS and Thales have a business objective; having a healthy business operation, but the NS also has a social purpose; to strengthen sustainable mobility in the Netherlands. The different requirements are highlighted in Chapter 4.

3. Inefficiencies in the current maintenance process

As proposed from the methodological framework in Chapter 1.5, this chapter looks at the current process of the maintenance the station resources of the NS. Once this has been mapped out, the inefficiencies can be determined. As a first step, it is important to create insight into the main actors that need to be taken into account in this research, this has been done by a stakeholder analysis in Appendix 4. It is essential to know who the important actors are, because with that information, it can be determined which interests are involved during the development of the improved maintenance situation designs in Chapter 5. As expected, the NS, Thales and the travellers are the key players in this study, but also the mechanics and the authorities are actors whose interests must be taken into account. This is because the mechanics are the executors of the actual maintenance of the station resources and the authorities have a lot of power in setting rules. An example of a rule is the obligation for tendering projects from a certain amount of money. This has a major impact on the currents contracts and therefore inefficiencies between NS and Thales, see Chapter 3.1.

Subsequently, the current process is looked at in a qualitative and quantitative way. Subchapter 3.2 will describe what happens in the current situation at the NS and Thales when a failure of the station resources occurs until it is resolved in a qualitative way. This information has been gathered through interviews, informal conversations and observations while walking along with staff. The people who were spoken (the numbers of which can be found in Table 1 in Chapter 1.5), were the process manager at Thales (*No. 19*), a Thales mechanic (*No. 24*), a planner (*No. 25*), a qualifier (*No. 27*) and people from the Operation Centre (*No. 12* and *15*) at the NS. With the information collected and the feedback after presenting the findings to the persons concerned, the correct current process flow could be established.

Subchapter 3.3 looks at the current process in a quantitative way, on the basis of a data analysis. During the data analysis the complete picture of all maintenance activities from both NS as Thales side was examined. All incidents were analysed over the past three years and about the failure data of December 2018 even more detailed information was available. The raw data from Service Now, the electronic system in which all information about failures is kept, has been obtained by the Information Analyst Station resources of the NS (*No. 7*) and the application manager of Thales (*No. 26*).

As a result of Chapter 3.1, 3.2 and 3.3, the current process has been mapped out in various ways and the discovered inefficiencies can be described. Answering subquestions 3 and 4.

3.1. The history between NS and Thales

Even before the OV chip card was developed, the NS already had KVAs and LBSs. The maintenance for these resources is laid down in the TODI (Technical Maintenance Decentral Infrastructure) contract and outsourced to Vialis via a European tender. Due to the fact that NS did the maintenance themselves beforehand, NS exactly knew what contract they were looking for.

When the OV chip card was developed, the NS was looking for a way to close railway stations and to find a way to check in and out. The NS has put this out to tender and as a result, a system was developed for the NS by the East-West company, which received the order in 2003. This consortium consisted of the companies Accenture, Thales and Vialis, with the main subcontractors MTR Corporation and Octopus cards Limited (both from Hong Kong). Within this so-called OVCP (Public Transport Chip Card and Gates) contract, NS hands over the risk and knowledge in the form of a full-service contract.

Accenture stepped out of the project in 2006 and in 2010 Thales also acquired the shares of Vialis. Thales Transportation Systems (TTS) in Huizen was set up as the leading entity to deliver all services. With the takeover contract for the maintenance of ticket vending machines and counter systems went to TTS. Earlier of Vialis, the NS service in 2004, Vialis already took over this service contract including the staff from Getronics. The contract was drawn up in mid-1998 between Getronics and NS, after Getronics took over part of the Telecom department during the privatisation of NS. In theory, technicians who now work for TTS might have previously worked for the NS.

In conclusion, because two European projects have been tendered at two different moments, there are currently two different contracts with NS and Thales; the TODI and OVCP contract. Further explanation about the SLAs from these contracts can be found in Chapter 4.

The disadvantage of the OVCP contract is that the provided service was completely new. Nobody did exactly know how the OV chipcard and the required resources would develop. It therefore was difficult to estimate the needs and risks of the contract. Any uncertainty automatically leads to high costs. Also, all agreements were set at the beginning for the duration of the entire contract. This also is a disadvantage, because needs develop over time. The contract does not match changing circumstances which creates undesired situations for all main actors. As an example, the NS and travellers would like the urgency of a disruption to be taken into account. Although Thales may also want this because their main objective is also to give travellers a pleasant travel experience, they are charged by the NS for the current SLAs (Chapter 4), so they only take the type of disruption into account, see Chapter 3.2 for further explanation. In this example, the contract is a barrier for the desired maintenance behaviour. This problem works both ways. Because Thales also would like to adjust the SLAs to have more solution time for an incident, so that they can plan their work better and more efficiently. Current contracts and SLAs do not allow more flexibility.

Inefficiencies

The inefficiency that comes from this subchapter arises from the rules that are part of European tendering. Agreements for the OVCP contract had to be made in advance, while the need was still uncertain and situations could change over time. Due to new insights, any new contract would be laid down differently if it were agreed again. This mainly concerns different SLA maintenance arrangements for the preferred situation, in order to meet the current wishes of the main actors. In addition to that, costs also play a role. The risks that were determined in advance, turned out to be lower than expected, so the NS now actually thinks they pay too much to Thales. Meanwhile Thales believes that the costs have become too high because of the SLAs that they have to meet. These statements were made by *No. 1* of the NS and *No. 18* and *19* of Thales.

Interviews show that the goals of the different companies do not lead to inefficiencies, because both want to give the traveller a nice trip without station resource disturbances. Nevertheless, their interests differ: Thales having a business model on making profits, the NS also having a social function. If a station resource is a nuisance, the traveller will blame the NS for this and not Thales.

With this information, sub-question 2 "*Does the function, history and goals of the companies affect the efficiency?*" of the research question is answered.

It can be concluded that the inefficiency that emerges from this subchapter is:

- Inefficiencies through permanent contract European tender while the desired situation was unknown

3.2. The process flow of the current maintenance system of incidents

This subchapter will describe the current process situation at the NS and Thales from the moment a failure of the station resources occurs, until it is resolved. Repairing an incident handling to cover the Netherlands, roughly takes place at 3 locations. 1) The NS BSM Operation Centre in Utrecht, 2) the Service Operator at Thales in Huizen and 3) the mechanic who solves the incident on location. In this subchapter, the process of resolving the incidents is displayed in a process flow, see Appendix 6. Since this is a big figure, the process is divided into three smaller parts. The first part is the moment when the failure is reported and processed by the NS and Thales, until a mechanic gets started in part two. In this part, the interactions between the NS and the mechanic are visible. In the third part, the process is made visible of the completion and closure of the failure by both the NS and Thales.

A general remark for the understanding of the process flow is that the NS and Thales have been working together since November 2018 in the same electronic system called Service Now. This system contains all the information about the incidents and proactive maintenance carried out by Thales. Service Now from the NS and Thales are still two separate worlds, but it is now possible to e-mail the same fields to each other more conveniently than before.

The information in the orange data blocks in the process flow contains information from Service Now.

NS BSM operation centre 1.1-1.4

Figure 9 shows the start of the process flow. When a failure occurs at a station resource, this is passed on to the NS Operations Centre. This can be done via a multi-channel, namely by mail, telephone, but usually this is done automatically by the monitoring system. This system monitors the functionality of all station resources, and when a malfunction occurs, this is automatically forwarded to the NS operations centre. The failure is turned into an incident, see step 1.1. Next, the solution group is assigned, 1.2. In most of the cases Thales is assigned for station resources that cannot be reset remotely by the NS, then a task is created for Thales 1.3. If this is not the case, the incident is passed on to another solution party and this falls outside the scope of this research.

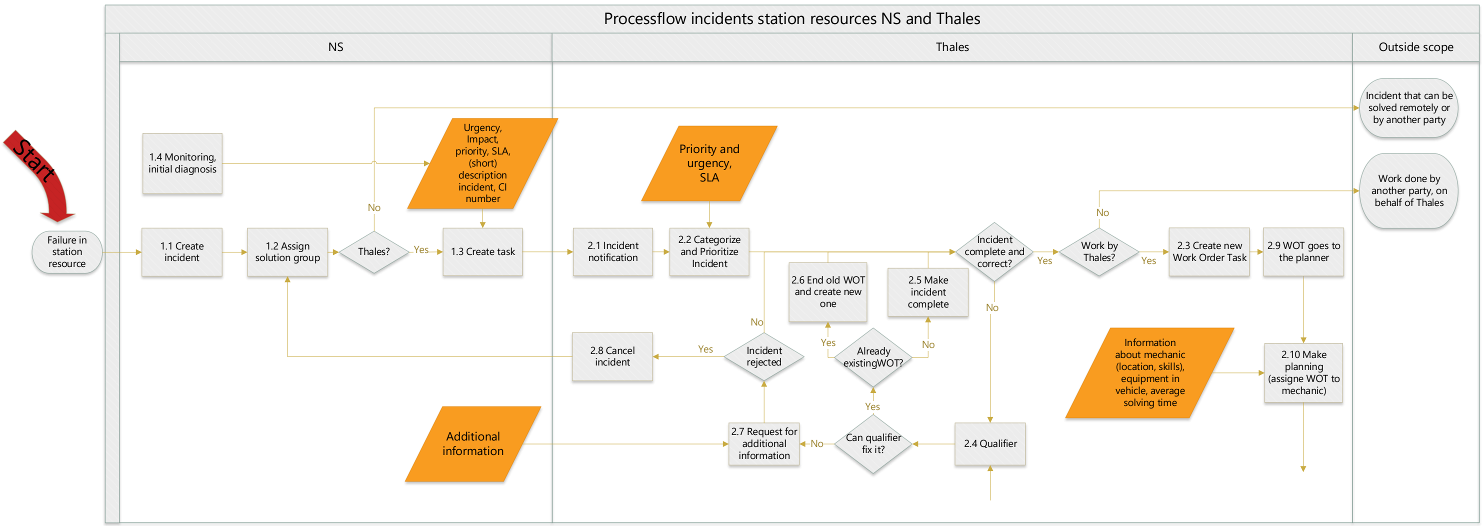

Figure 9, Process flow start of an incident - NS BSM operation Centre and Thales Operator Service

The task contains information about the incident. First, a template (short description) is linked to the incident, for example "POO-gate doors defect". This template has an automatic impact and urgency, from which the priority and the SLA (service level agreement) are determined, see Figure 10. The CI (Configuration Item, in other words; equipment item) number is then added to the task, which contains information about the station resource itself, such as the type of machine and the exact location on the station. More detailed information can be sent on the failure. For example a notation about faults and repairs that have taken place on the same device in a short time and how this kind of failures can be resolved better in the future. This information comes from the analysis team, product managers and/or the Operation Centre of the NS, 1.4.

Figure 10, Impact and urgency standardisation NS

When all information has been entered, the incident is forwarded to Thales, 2.1. As soon as Thales receives the incident, the SLA time starts running.

The Service Operator at Thales 2.1-2.10

When Thales receives an incident, the incident is also categorised and prioritised on the Thales side, 2.2. This differs from the NS prioritisation, it only looks to the SLA which is given to the incident. So it is not important what the final priority is of the NS of the incident (1-5), only the SLA counts. Once this has been established, it is checked whether the incident is complete and clear. If this is the case, a Work Order Task (WOT) is created, 2.3. In case of any unclarities, the incident goes to the qualifier, 2.4. Here the qualifier checks if the incident can be completed by himself, 2.5, or if the NS must be contacted for additional information, 2.7. This is especially the case with CIs that are send from the NS, but are unknown to Thales. The NS selects a CI when there is a malfunction, but if it does not match the CI number in the Thales Configuration Management Data Base (CMDB), Thales does not know which CI is meant. This can occur because new (temporary) equipment has been installed or the numbering of existing equipment has changed, but the NS CMDB has not been updated with the CMDB of Thales.

In addition, it may also happen that other templates are used as usual or that something deviates in the title of the incident that the NS sends to Thales, then the incident will automatically end up at the qualifier. An example of this is when the standard template talks in the singular form about a certain malfunction, but then an employee of the Operation Centre of the NS communicates in the plural form. Then the standard template no longer matches and gives a deviation, which means that the incident must be checked by the qualifier. Fortunately, the qualifier can often adjust the incident independently so that it is still approved and goes to the planner, unless the meaning of the description given by the NS is unclear and additional information is needed.

It might also happen that an incident was not intended for Thales, in that case, the incident is cancelled, 2.8, and on the NS side assured to another group 1.2. An example of this, is a report by mail from station management concerning a broken machine. The logical assumption could be that it concerns a KVA (ticket machine), but the moment the Thales mechanic comes to the site, it turns out to be a candy machine. This machine is not covered by the maintenance of Thales, so the incident is cancelled at the side of Thales and forwarded to another party by the NS. Here the information was not complete and unnecessary inefficiency took place.

Unfortunately, nothing can be said about the qualitative amount of this kind of inefficiencies because it is not documented. The issue only emerged from interviews with the planner and qualifier from Thales.

If the incident is not rejected and the information has been completed, a WOT will be created, 2.3. When the WOT of an incident is created, the WOT is dispatched to the planner 2.9. The planner makes a schedule based on information about the mechanics at work, such as skills, the location of the mechanic and failure, spare parts in the car, travelling time and the average solving time of the failure, 2.10.

Mechanic at Thales

The majority of the Thales mechanics are dedicated to a PTO (Public Transport Organization). This means that a mechanic can only carry out maintenance on equipment for the NS (or any other customer) on an exclusive basis. This can cause extra travel times, while malfunctions could have been combined if mechanics were shared over multiple companies. In contrast, Thales has divided mechanics into five service areas (regions), which in turn reduces travel time.

Figure 11 shows the process flow from the mechanic at Thales. When the planner has assigned the WOT to a mechanic, the mechanic must confirm it, 3.1. When he has done this, he can see the information that the NS has sent in step 1.3 about the failure and a manual is sent with the WOT on how the particular equipment item or failure should usually be resolved. Experienced mechanics usually do not look at this, but this is especially useful for mechanics with little experience. Also, information is available on all repairs and notes in the history of the same device. It differs per mechanic how extensively this is looked at.

All information about the incident can be seen on the smartphone, tablet or the green booklet (a physical booklet stored in each gate and KVA). There is a lot of information available, but because it is so much, a mechanic only looks at the things he thinks are important and because of this many useful functions are barely used. The information is available but is not used properly.

An example of this inefficiency is with repeated disruptions. When a CI repeatedly interferes in a short time, a report should appear, to remind mechanic that it has recently disturbed CI and what has been done about it. This prevents unnecessary and useless duplication of work. As a result, the number of repeat failures will decrease and a resource will be fixed at once, or in the worst case at twice. Instead of an incident at the same CI that keeps coming back several times and where the standard solution method is always applied, while this is apparently not the structural solution of the problem, see data analysis Chapter 3.3.3 on repeat failure.

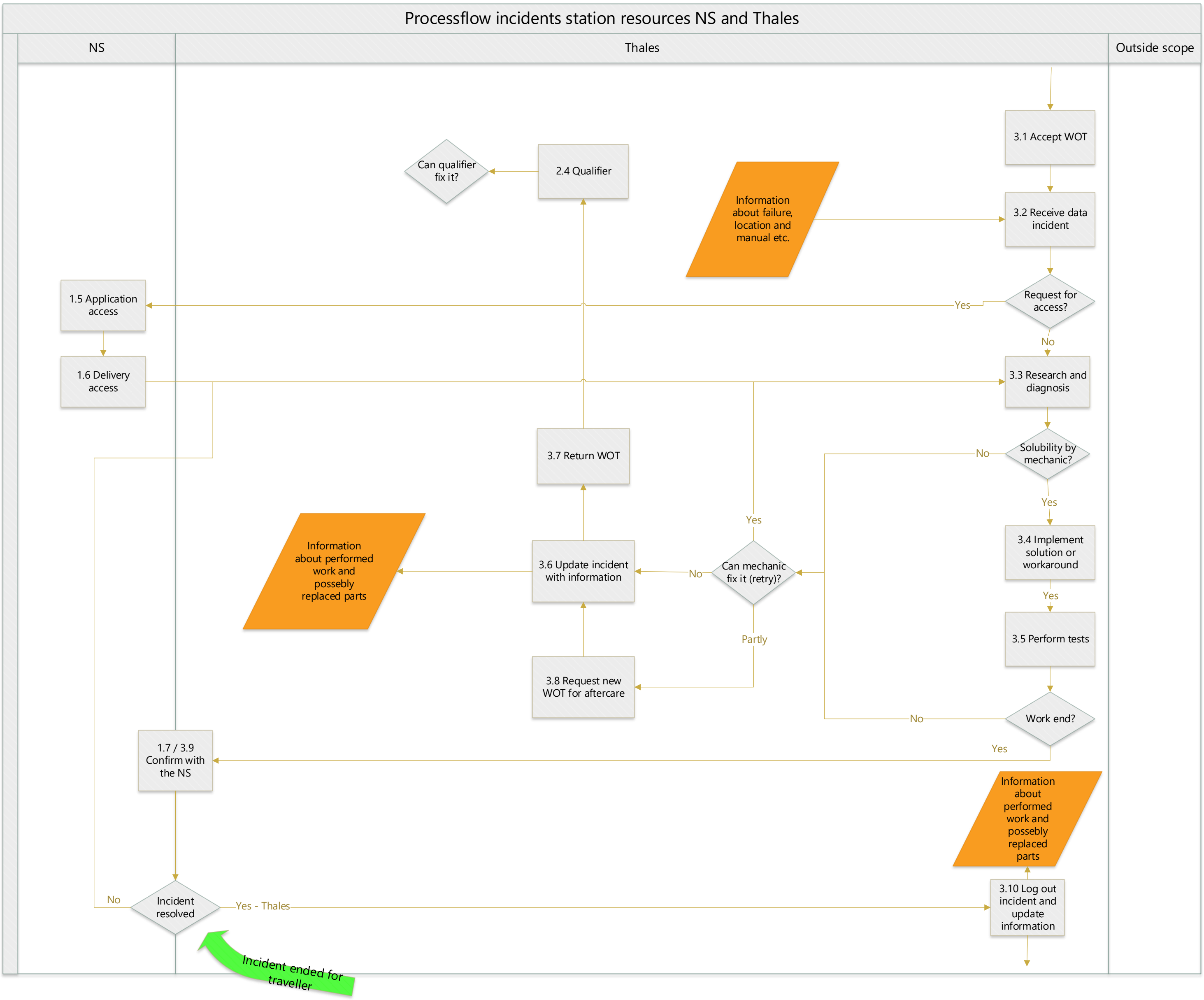

Figure 11, Process flow from the moment the mechanic has accepted the WOT

When the technician has received the data, 3.2, he goes to the location. It may be that he needs to have access to solve the failure, such as a router at a station. This access must be requested, 1.5, and given, 1.6, by the NS. The mechanic can then start his investigation into the cause of the incident, 3.3. For the investigation, a mechanic acts according to a flow chart or from experience. First, a reboot is examined to see if an incident can be resolved, if that is not the case a check is made to see whether parts need to be replaced. Parts are replaced when necessary, but if the incident can be solved in another way, it is more desirable due to the associated costs for NS. If a device interferes very often, it can be decided, in consultation with the NS, to replace the device completely.

If the mechanic finds out during the repair that a part must be replaced, but he does not have this part with the spare parts in his vehicle, he cannot solve this WOT and will update the incident with the necessary information, 3.6, and send the WOT back 3.7. This comes back again with the qualifier 2.4. The qualifier will close this WOT 2.6, and create a new WOT for a mechanic who has the required part in his car, so that the incident can still be solved. In practice, there can be several WOTs under each incident.

In some cases Thales cannot solve the incident. They have engaged third parties to support them, for example, in case of glass damage to gates and barriers. When the diagnosis shows that there is glass damage to a gate, the mechanic can solve the WOT partial by making the situation safe, and he will look at whether the gate can remain in use temporarily. The SLA stops after this. The mechanic will then make a request for a new WOT for aftercare, 3.8, will add photos of the damage, 3.6, and will send his WOT back to the qualifier 2.4.

If the mechanic can solve the incident himself, he will do so 3.4. He will then run tests, 3.5, to see if the incident has been resolved. If this is not the case, he can try again, back to 3.3, or it may be that the technician does not have enough skills to solve the incident, he will update the incident with information about what he has tried 3.6 and send back 3.7 so that the qualifier can create a new WOT and send another mechanic with more experience. When the mechanic has solved the incident, he must confirm this with the NS, 3.9. This is done by telephone. The NS BSM Operation Centre checks in their monitor systems whether the failure has been rectified and if this is the case, the mechanic can close his WOT after he has filled in all the information about his work. This is both in the electronic system of Service Now and in a physical booklet in the station resource itself, 3.10. If this is not the case, the diagnosis will start again to the cause of the incident 3.3.

Thales did not want to provide insight into the number of WOTs per incident because this is too sensitive information about the efficiency of their function. However, it can be concluded that there is an inefficiency because several WOTs are needed due to missing spare parts in the mechanic's vehicle, lack of skills of the mechanic, the involvement of a third solution party or the necessary aftercare.

The Service Operator at Thales 2.11-2.13

Figure 12, shows the process flow of the completion of the failure on both the NS and Thales side. When a mechanic closes the WOT, the service operator (planner), checks whether everything he has filled in is correct, 2.11. If this is correct, the incident can be closed 2.13, but if this is not the case, there will be contact with the NS to close the incident properly, 2.12.

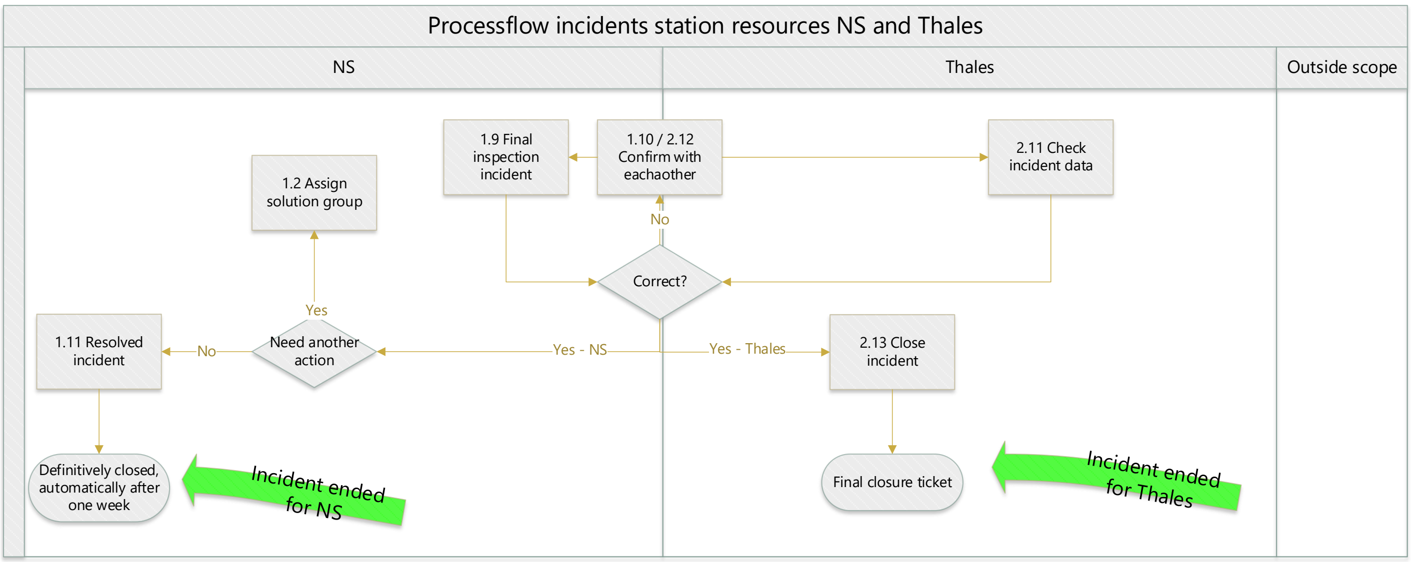

Figure 12, The process flow for the completion of the failure

An example: when a mechanic has installed a mobile validator, he then must be checked at the Operation Centre at the NS whether the resource is functioning correctly. However, if he did the installation of the validator outside working hours of the Operation Centre, the mechanic will close the WOT with the announcement that the qualifier must check with the Operation Centre at the NS the following morning to see whether the work has been performed well. In addition, it sometimes happens that additional contact must be made because the mechanic has not fully or correctly entered the information about his work in the incident in Service Now.

NS BSM operation centre 1.7-1.11

If the technician confirms with the NS if the incident is resolved and this is the case, the task that was created in step 1.3 is resolved 1.8. After this, a final inspection, 1.9, follows whether all information about the incident has been entered correctly in the electronic system. This is the same as 2.11 at the side of Thales, but this also happens at the NS side. If the information is not correct, they have contact with Thales, 1.10, the reasons for this are explained in 2.12. If the information is complete and correct, it may be that follow-up action is required from the NS. If this is the case, the incident will be assigned to another group than Thales, 1.2. If this is not the case, the incident will be resolved, 1.11.

With information about the current process at the Operation Centre at the NS, the Service Operator at Thales and the work of the mechanic, sub-question 3 "*What is the process flow of the current system?"* of the research question was answered.

Inefficiencies

Various inefficiencies emerge from this analysis. In Appendix 7 and 8, the impact of the various steps both for passengers and the NS and Thales is shown. Everything coloured green in these figures gives a positive impact and everything that is coloured red shows a negative impact. Even though all main actors want minimal impact for travellers, delays often are embedded in the dissolving processes.

It can be concluded that the emerged inefficiencies in the flow analysis process are the following:

- NS and Thales have a different classification for the same incident. This is an inefficiency because information, the priority in this case, is sent along with no further action. This is because the NS assesses Thales on the service they provide and this is determined on the basis of the SLAs. So a planner only deals with Thales's interest and not with the requirements of the traveller and thus, indirectly, the NS.
- Double processes due to fact that incident information is not complete, correct or clear at the beginning of the report or after resolving. If this is not the case, additional actions and contact are required (2.4, 2.5, 2.7, 2.8, 2.12, 1.10), which takes time for all parties.
- Disruptions that are reported to Thales, but are outside the contracted scope. This is also detrimental to the final dissolution time, even though it ultimately falls outside the scope of the research.
- Inefficient work planning. With a 4-hour dissolving time in the case of fatal disturbances, it is almost impossible to plan. This is laid down in the contract but results in inefficiencies in the process. Because this eventually creates inefficient routes, which means that the dissolving time is longer than when efficient planning can be made.
- The majority of the mechanics are PTO-specific, which means that they cannot carry out work of other public transport companies that are also a customer of Thales. This causes inefficiencies because a shorter travel time and therefore a shorter dissolving time can be achieved if mechanics could solve equipment from other transport companies.
- The mechanic has a lot of information but does not use it usefully. This leads to both extra work and therefore costs for the NS and Thales as well as a nuisance for the traveller.
- Multiple WOTs per incident. It is possible that a mechanic does not have the right skills or the right material in his vehicle so that the WOT is sent back 3.7 to the qualifier 2.4 and another mechanic needs to repair the station resource. In the event of shortage of material, the

inefficiency may lie in the vehicle's content of the mechanic or the more efficient planning of the mechanic's work. Extra WOTs ensure that an incident cannot be resolved at the first visit. This ensures a longer dissolution time and therefore more nuisance for the traveller.

- Telephone contact mechanic and NS after resolving the incident. In step 1.7 / 3.9 after solving every failure, a mechanic must contact the NS by phone before he can proceed to the next incident. For all parties, this is an inefficiency because mechanics are delayed in proceeding to the next incident and at the NS the people of the Operations Centre are also being deprived of their time.
- Notation of work done by the mechanic, both in Service Now and in a physical booklet. This is double work for the mechanic and in addition information in both sources often does not match (more extensive than the other) and the text in the fictitious booklet can sometimes not be read because of illegible manuscripts. This provides information asymmetry.
- When it turns out at 1.9 that another action is needed from the NS for the definitive closure of the incident, or Thales was not the right party to solve the incident in the first place, this also creates extra dissolution time, and the impact on the traveller is therefore negative. However, this falls beyond the scope of the work, because this has nothing to do with the cooperation between the NS and Thales.

3.3. Data analysis

In this subchapter, there is looked at data about failures of the station resources of the NS, to get a better understanding about the periodic maintenance, the failures and their causes and how they are solved. First, in Subchapter 3.3.1 there is looked at the complete picture of all the maintenance on the station resources that the NS (from a distance) and Thales perform. Then the introduction states that there are about 300 failures per week handled by Thales. Subchapter 3.3.2 and 3.3.3 will discuss this amount in more detail. In Subchapter 3.3.2 there will be looked at all incidents of the past three years and in Subchapter 3.3.3 there will be deeper information about the data of December 2018.

The equipment numbers come from the CMDB of the NS and the data used for the data analysis is the excel output of Service Now from both Thales and NS. If it had been indicated that the incident had been cancelled, it was removed from the data in order to prevent noise, because one time "the incident" was still in the data of the NS and not at Thales or vice versa. So only those incidents that have actually been resolved have been looked at.

For the analysis, the data from Service Now was disaggregated by resource type and from these different types, there was first looked at how many incidents occur on average. Subsequently, the ratio of fatal versus non-fatal failures was determined, the dissolution time was calculated and the causes and solutions of all failures were mapped. In addition, there was also looked at how many failures occur after a software update, this information is kept from reports by Thales. Finally, there was looked at repeat failures by looking how often identical CI numbers occurred. The results will be presented below.

This data analysis will ensure that the current situation is tested in a qualitative way, with real data from the process. The result is that inefficiencies from this data can be named at the end of this subchapter a part of sub-question 4 can be answered.

3.3.1. General information about maintenance

This subchapter will give a complete picture of all the maintenance that the NS (from a distance) and Thales perform, but first, it is interesting to look at the availability of the station resources in Table 5 below. What can be seen in this table is that the average availability is always above 99.15%. This means that there is little downtime. However, if one zooms in on the high average availability, it appears that resources are sometimes out of service for a long time, which is a nuisance for the traveller. The 99% availability can therefore give a distorted picture.

Table 5, Average station resource availability 2018

Station resource		Number of resources	Average availability over 2018
KVA	E2000	129	99,47%
	E2006	618	99,15%
	AVM	165	99,59%
LBS		127	99,36%
CiCo		1409	99,93%
SA		1690	99,98%
Gates		1590	99,73%

It is striking to note that, with the exception of the information and alarm columns (SA), the equipment from the TODI contract (E2000, E2006 and Desk Systems) has the lowest availability compared to the OVCP (CiCos and gates) contract and the AVM machines that are under contract with Scheidt & Bachmann. Perhaps this can be explained by the different incentives that they have from the different types of contracts.

In the TODI contract, Thales is paid every time they come on location to resolve an incident. When they come back the next day because the incident was not resolved correctly, they get paid again. This doesn't stimulate stakeholders to seek for more efficiency. OVCP, on the other hand, is a full-service contract where Thales receives a fixed amount for the maintenance of the gates and the CiCos. The more efficiently they organize this, the more profit Thales will have. With the AVM machines, the Service Level Agreements depend on the availability. This is therefore another incentive for organizing maintenance.

However, no conclusions can be drawn from the data in Table 5 because it are all other devices. For example, the AVM is technically simpler than the other KVAs and has no currency sales (biggest cause of failures at KVAs). As a result, availability may be higher, but in addition, the period in the field may differ. AVMs have only been on the stations since 2015, while most KVA resources have been stationed for much longer and can therefore show signs of wear and tear.

In addition to availability, Figure 13 shows an overview of all the maintenance that is done at the station resources. Firstly, the maintenance that is carried out can be divided into periodic and reactive maintenance that take place at the various station resources. These are both different service packages for Thales, see Appendix 4, but both can cause inconvenience. Because even with periodic maintenance, resources are temporarily out of order, see Chapter 4 for more explanation about nuisance to travellers.

In Figure 14 below it can be seen how much periodic maintenance Thales has added to the different station resources types. A

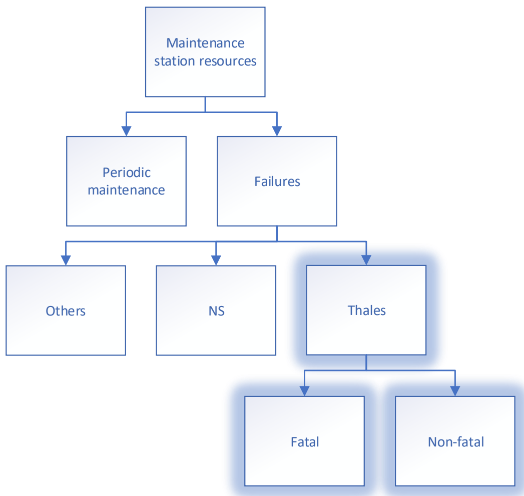

Figure 13, Overview of maintenance structure distinction is made between the maintenance of ticket vending machines, namely the ET2000 and the ET2006. This is because they are two completely different devices on the inside in terms of technology.

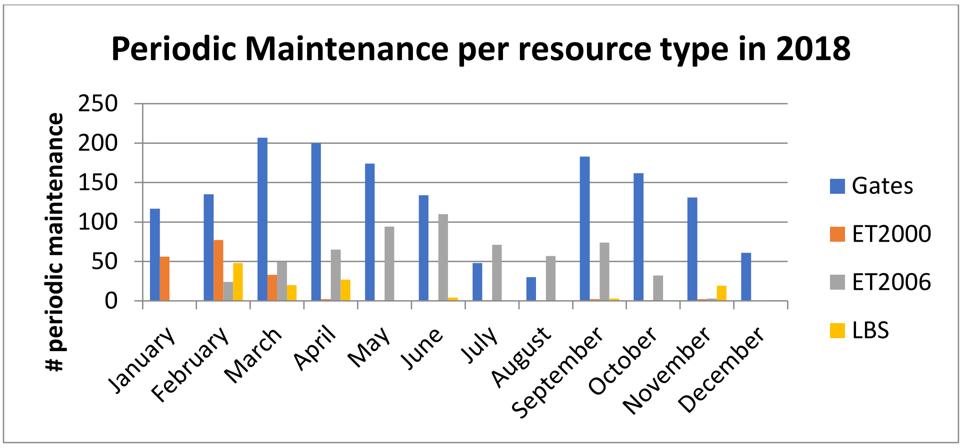

Figure 14, Periodic maintenance 2018 per resource type

From these data it can be concluded that periodic maintenance is only carried out for ticket sales automates, Desk Systems and gates and no periodic maintenance is carried out at the CiCos, AVMs and the SA columns.

Since 2018, the method used by Thales for regular maintenance has changed from standard two times a year to maintenance based on use since 2018. If a resource is used more often, it receives more periodic maintenance and vice versa. In addition, a distinction is made between major periodic maintenance of the entire device and small periodic maintenance of sensitive parts. Both types of periodic maintenance are added together in Figure 14. Figure 15 shows an overview of all the periodic maintenance from the past 3 years.

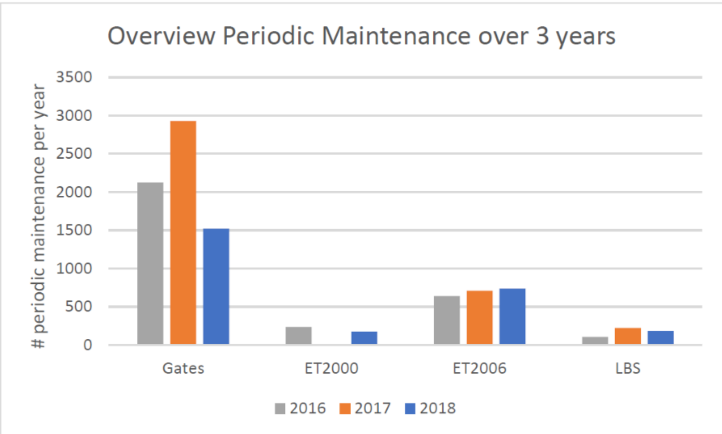

Figure 15, Overview periodic maintenance last 3 years

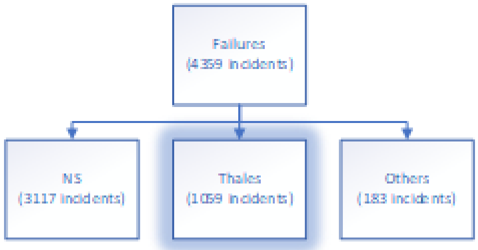

Figure 16, Breakdown of all incidents at the station resources

In 2017, 200 new gates were installed compared to 2016, which increased the number of periodic maintenance. Despite the new approach in 2018, periodic maintenance at the gates has decreased. In 2017 no periodic maintenance was performed at the ET2000 because these would all be replaced. This plan has been reversed, so that periodic maintenance was carried out again in 2018. In conclusion, the total of regular maintenance in 2017 was 3861 and in 2018 the number was 2616.

In addition to periodic maintenance, reactive maintenance is carried out. The incidents that take place are explained in more detail from December 2018 in Figure 16. This month is used because Chapter 3.3.3 discusses these data in more depth. In December 2018, a total of 4359 failures occurred at all station resources. Of these, 3117 could be remotely resolved by the NS via reboots. Especially the gates and the E2006 devices (both more than 1400 reboots) were remotely repaired. What cannot be repaired by the NS is solved by Thales, namely 1059 incidents, or other parties. Other parties that solve incidents besides Thales are parties such as G4S, Strukton and KPN. Only the Thales incidents fall within the scope of this research and are therefore explained in Chapter 3.3.2 and 3.3.3. Thales distinguishes between a fatal and a non-fatal failure in the event of a failure. This has to do with the SLA agreements that have been made between the NS and Thales, Chapter 4.

The definition of a failure and when this is fatal or not, is the following: *"A failure is when a station device can no longer perform its function. A distinction is made between a fatal failure and a non-fatal failure. An incident is fatal when the main functions of the equipment are no longer available"* (NS, 2018). For gates and CiCos, the most important task is the check-in and passage of travellers and a ticket machine needs to provide travellers with a ticket. An incident is non-fatal when there is an incident, but the main functions of the equipment are still available and the failure it is not obstructing the traveller to perform a successful journey.

3.3.2. Incidents over the last 3 years

This section shows the total number of incidents solved by Thales per month during the past 3 years, see Figure 17. In 2016, these averaged 1,118 incidents per month, compared to 1191 incidents per month in 2017 and 1047 in 2018.

It can be seen that the number of faults is fairly constant over the various months. There is no relation between a decrease or increase in a certain period per year, for example, due to holidays or certain weather conditions. The ratio between preventive maintenance and reactive maintenance is 16% vs 84% in 2018.

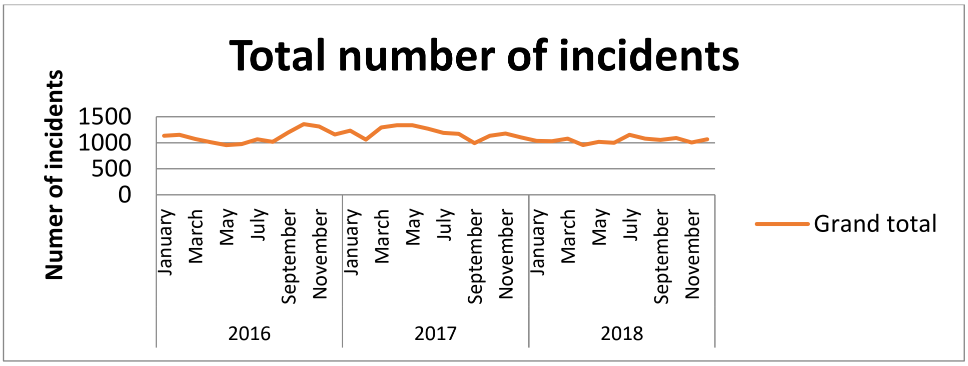

Figure 17, Total number of incidents in the last 3 years

It is striking that the number of incidents has remained relatively constant and even decreased slightly, even after placing 200 extra gates in 2017 and the changed strategy of periodic maintenance in 2018 (see Chapter 3.3.1). While one might expect that if fewer periodic maintenance is performed, the incidents will increase. However, it appears that the new strategy, based on the use of resources, is more efficient because the number of incidents does not increase, while maintenance decreases.

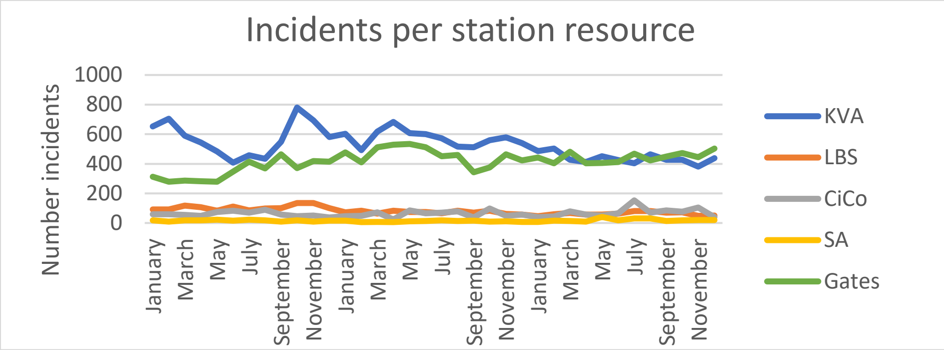

Figure 18, Distribution of the station resources per type during the past 3 years

Subsequently, a distribution of all these incidents was made per station type, see Figure 18. It can be seen that the ticket machines and service desks give the most incidents. Table 6 shows the number of resources per type in the field. This way there can be looked at the ratio of failures per station resource.

Table 6, Overview of the total number of incidents and resources per type from the last 3 years

	KVA	LBS	CiCo	SA	Gates
# incidents	19000	2879	2332	564	15037
% of total incidents	47,2%	7,2%	5,8%	1,4%	37,4%
# resources	912	127	1409	1690	1590
% of total resources	15,9%	2,2%	24,6%	29,5%	27,8%
Ratio # resources vs # incidents	**20,8**	**22,7**	1,7	0,3	**9,5**

Looking at the number of resources and the number of failures per object type in the past 3 years, the conclusion can be drawn that the ticket machines, service desks and gates are disrupted the most proportionately.

3.3.3. Incidents December 2018

In this subchapter, there is looked at all the failures that took place in December 2018 in more depth. There is looked at this period because the NS and Thales both have been working with Service Now since November 2018, so the export of both systems can be put together more easily than before. In addition, Figure 17 shows that the number of incidents did not vary much per month, so each month could have been chosen. Only not November 2018, because then the systems still had to be connected and there were still some start-up problems, so this data was not representative of an average month.

In total, 1050 incidents were reported to Thales in December. Plus 9 incidents in the "others" category, however, these are not included in this analysis because this often concerns barriers between the gates and therefore does not fall within the scope of this investigation (only validation and sales equipment) and these equipment item also has a very long dissolve time, because Thales cannot replace glass itself and a third party is doing the repair.

Table 7 shows the number of fatal and non-fatal incidents per resource type, in Table 8 the resolution time of an incident per resource type is shown and Table 9 looks at the cause of the incident. Eventually, there is something said about software releases and repeated disruptions in this Subchapter.

Table 7, Number of fatal and non-fatal incidents in December 2018

December 2018	KVA		LBS		CiCo		SA		Gates		Total	
# incidents	441		48		39		21		501		1050	
Fatal	421	95%	42	87%	31	79%	21	100%	425	85%	940	90%
Non-fatal	20	5%	6	13%	8	21%	0	0%	76	15%	110	10%

Table 7 shows that most failures are fatal and it shows that CiCos and gates have the most disturbances that are not fatal. Non-fatal failures at CiCos are, for example, failures where the display is not legible but still functions. At gates, this is for example when the gate makes a noise, or the doors linger. It still functions, but not optimal. From the historical data on this subject (see Appendix 9) it can be seen that the percentage of fatal disruptions in 2018 was almost always between 85% and 95%.

Table 8, Resolution time of an incident per resource type

December 2018	KVA	LBS	CiCo	SA	Gates
# incidents	441	48	39	21	501
Average duration of failure	6,43u	4,12u	9,26u	5,96u	6,31u
Minimum	0,32u	0,66u	0,23u	1,09u	0,07u
Quartile 1	2,02u	2,04u	2,73u	2,03u	1,88u
Median	3,19u	2,83u	5,08u	2,91u	3,11u
Quartile 3	5,60u	4,16u	15,05u	4,01u	4,99u
Maximum	170,1u	18,92u	30,69u	28,86u	138,41u

The average resolution time of all station resources failures is 6 hours and 36 minutes. This also includes the time that Thales does not work. According to the SLAs, see Chapter 4, they have certain work windows, but it has been decided not to include these windows in the data analysis, because also outside these windows the traveller can experience inconvenience if a failure occurs.

Table 8 shows the solution time per resource type according to the SLA agreements that have been made, a fatal failure must be resolved within 4 hours and a non-fatal failure within 72 hours. Further explanation about this is in Chapter 4. The average dissolution time is much higher than the SLA agreements. However, this is strongly influenced by some failures that took a long time to solve. Table 4 and Figure 19 show that the minima and maxima are widely removed in terms of the resolution time of a failure, but that the median is often within 4 hours, only not for the CiCos. So looking at the median says more about the actual numbers, than looking at the average duration of the failure, because the latter is too much influenced by outliers. The box plots below give a good idea of the variety in the dissolution time.

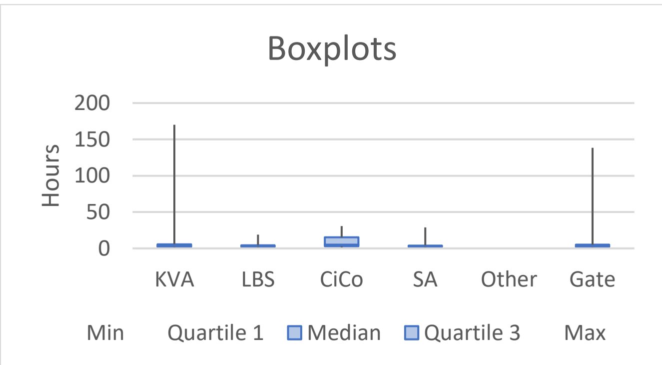

Figure 19, Boxplot of the resolution time of all resource types

Table 9, Cause of the incidents

December 2018	KVA		LBS		CiCo		SA		Gates	
# incidents	441		48		39		22		501	
Users error	31	7%	11	23%	1	3%	-	0%	24	5%
Hardware	**222**	**50%**	**30**	**63%**	13	33%	7	33%	188	38%
Software	73	17%	2	4%	**20**	**51%**	**11**	**52%**	**232**	**46%**
Vandalism	67	15%	0	0%	2	5%	1	5%	50	10%
Cause external	42	10%	5	10%	3	8%	2	10%	7	1%
Unknown	6	1%	-	0%	-	0%	-	0%	-	0%

Table 9 shows the cause of all incidents per resource type. Hardware, software and vandalism failures speak for themselves. A user error is an error that is caused by the user itself; the traveller or an employee of the LBS. This is, for example, if someone puts a wrong coin (damaged, or foreign money) in the KVA. An external cause of a failure is when an external party doing something at a machine and as a result it fails , for example, a failure caused by G4S. At last, there is the category “unknown”. This category is assigned when it is not clear what exactly is the cause or the mechanic has forgotten to fill in the input field in Service Now when handling the malfunction. For ticket machines and Desk Systems, most of the disruptions have to do with hardware failures. At CiCos, SA's and gates, most failures are caused by software errors.

Appendix 10 provides a more comprehensive overview of the problem codes that incidents from KVAs receive and the top 10 of components that interfere and shows an overview of the solution codes for all station resources.

Failures after software update

Nowadays, software is often developed via the Agile method. This means that software is not fully developed and tested because this can take a long time. In the Agile approach, one knows that a software release will not be good at once and it will be improved through incremental and iterative working. With incremental software development 'chunks' software are added to previously delivered software. Every increment adds new functionality. In the case of iterative software development, a very preliminary version is first built, after which it is reflected and then the software is adapted to the wishes (Jansen & van Tuil, 2019).

An important advantage of an Agile approach is the ability to respond quickly to change and need. The software of the station resources is also developed in this way. The advantage is that often updates can take place, but the data also shows that this has a disadvantage. Namely, when looking at the software failures in the incidents in January, because in December there were no software releases, the number of incidents at the CiCos increased from 128 to 167. This increase can be linked to software release on the 29th, 30 and 31st January. In addition, 20 gates also suffered from incidents caused by software failures. In some cases the NS can solve these problems remotely, but that was not possible with the release from January.

It is striking that the NS and Thales have agreed that the SLAs will be stopped temporarily when many disruptions occur after a software update. So Thales does not experience any (financial)disadvantages of the many disruptions after a release.

It can be concluded that software releases could ensure that the equipment functions better, but in addition, they also cause more disruptions, which can be a nuisance for the traveller. In 2018 there were 5 software updates at the gates and CiCos.

Repeat failures

The cause of a repeat failure differs each time. Of course, a device can accidentally break several times in a small period of time. But it is also possible that the mechanic has not repaired the device correctly and the failure appears again after a short time. Or it may be that due to a repair to a part, the mechanic will cause another failure to another part.

Table 10 shows that from the 1050 failures, in total 692 different devices failed in December. At 131 devices a malfunction occurs twice and there were 3 devices which needed 8 different repair visits this month to correct malfunctions. For this analysis, there is looked at how often a CI number occurred in the December data.

Table 10, Repeat failures on the same resource in December 2018

	2x	3x	4x	5x	6x	7x	8x
# times the same CI in December	131	41	22	6	2	4	3

An example of a resource that has created an incident 8 times is port POO553002005, see Table 11. The same malfunction occurred five times in a row, each time the mechanic rebooted the gate, but then the failure arose again. The conclusion can be made that this was not the necessary solution. Finally, on December 11, the board computer was replaced, after which the malfunction no longer occurred. On 23 December, a completely different malfunction was reported, vandalism to the barcode glass and on 24 December the gate did not give a check out beep.

Table 11, Eight times repeat failure of a gate

CI	Short description	Date
Gate POO553002005	No connectivity	3 December
	Is hanging in Software	4 December
	Is hanging in Software	5 December
	Is hanging in Software	9 December
	No connectivity	10 December
	EMM (board computer) replaced	11 December
	Barcode glass destroyed	12 December
	Gate does not give a check out beep	13 December

The last two failures did probably did have any relation with the first 6 failures. However, there are two remarks to be made with respect to repeated faults and efficiency here; 1) Repeating failures should be monitored more closely. If a CI fails multiple times and the standard solution does not work, there should be a more thorough look. It is logical that the equipment is not immediately replaced because that causes high equipment costs, but when a resource gives the same failure twice, it is necessary to look at another method of dissolving. When going too often for the same disruption, this brings high labour costs and a lot of inconvenience for the travellers. 2) If a device has many failures in a short period of time, where it does not matter whether they have the same or a different cause, consideration must take place whether it is more advantageous to install a completely new device. This again ensures high equipment costs, but multiple disruptions per month result in high labour costs and a lot of inconvenience for travellers. This consideration has to do with the balance between costs and benefits, explained in Chapter 2.2 about economic relevance.

Inefficiencies

The inefficiencies that emerge in this Subchapter can be divided into three causes. First of all, the ratio of fatal and non-fatal faults is often higher than disrupted see Chapter 4. The number of fatal faults is often higher, which according to the SLA have a short dissolution time of 4 hours compared to 72 hours at non-fatal failure. This makes the optimal planning of troubleshooting the faults more difficult. In addition, there are also repeated failures, this also counts as inefficiency, because this causes extra inconvenience for the traveller and extra (labour) costs for the NS and Thales. While this could have been prevented, or at least in some cases could have been noticed much earlier. Finally, the failures that occur after a software release. The Agile working method should bring benefits, but in the case of software updates for the station resources, they also cause more disruptions.

It can be concluded that the inefficiencies that emerges from this subchapter are:

- An inefficient planning for resolving malfunctions for Thales, due to the large amount of fatal malfunctions compared to the non-fatal malfunctions
- Repeat failures
- Failures after software releases

Conclusion

From the information about the history between the NS and Thales, the process flow- and data analysis, various inefficiencies have emerged. These inefficiencies are a result of unnecessary process steps, inattention of employees, but also from issues arising from the principal-agent relationship between the NS and Thales, such as trust issues and power imbalances that do not cause the desired behaviour at both the NS and Thales.

In the following Table 12, these inefficiencies are subdivided into the different types of waste from the literature, Chapter 2.4.2. The waste type "overproduction" is not included in this table, because it appears that this type of waste does not occur in the maintenance process of the station resources.

Sub-question 4 of the research question "*What are the inefficiencies of the current system?*" was answered with this information.

Table 12, Overview of the inefficiencies in the current system categorised in the waste types

Inefficiencies		Transportation	Inventory	Motion	Waiting	Over-processing	Defects	Correction	Knowledge disconnection
1	Undesirable behaviour due to the permanent contract European tender while the desired situation was unknown						X		X
2	Unnecessary contact and work because malfunctions are reported by Thales, but they are not the solution	X		X				X	
3	Undesirable behaviour due to different classification of incidents NS and Thales					X	X		X
4	Unnecessary contact and work because incident information is not complete at the beginning of or after resolving the incident					X	X	X	
5	The mechanic not correct and not useful use of failure information.					X			X
6	The occurrence of multiple WOTs per incident	X	X					X	X
7	No efficient work planning for Thales caused by: maintenance strategy, the amount of fatal vs non-fatal failures and PTO specific mechanics	X		X	X				

8	**Unnecessary contact and work caused by telephone contact mechanic and NS after resolving incident**				x	x			
9	**Unnecessary work by the mechanic because work notation needs to be both in Service now and physical booklet**					x			
10	**Unnecessary amount of failures and work due to repeat disruptions**	x		x			x	x	x
11	**Unnecessary amount of disruptions and work due to software releases**						x	x	

The inefficiencies in Table 12 ensure that the requirements of the main actors in Chapter 4 cannot be achieved. There is, however, a difference between inefficiencies that occur with every failure, such as *No. 1, 3, 7, 8* and *9*, and inefficiencies that occasionally occur such as *No. 2, 4, 5, 6, 10*, and *11*. It can be concluded that the inefficiencies that occur in every process are the most important to resolve in Chapter 5, because these structurally ensure that the requirements are not met. However, when inefficiencies *2, 4* and *6* occur, this results in repeated processes that deteriorate the dissolving time and inefficiencies *5, 10* and *11* cause more work because more failures occur than necessary. That is why the inefficiencies that occur sporadically should also be included when drafting the solution designs, but improvements for solving structural disruptions have the highest priority.

The above inefficiencies in Table 12 are the result of not applying the correct maintenance strategy and not correctly pursuing how economic optimization can be achieved. However, in addition to these two things, the principal-agent relationship between NS and Thales is also a reason for these inefficiencies. According to the literature, the inefficiencies that arise from the principal agent cooperation are caused by three things; power imbalances, trust issues and the lack of willingness of partners to change behaviour in favour of the other party (Hingley, Lindgreen, & Casswell, 2006), (Xiande Zhao, 2002), (Pereira, 2009). In this case, according to interviews (*No. 1, 14, 15, 18, 22, 25* and *27* see Table 1), it seems that there is a willingness to change behaviour from both companies, however, people are not really aware of the necessity and benefits, so hopefully, this research will contribute to this. Subsequently, the power that the NS performs on Thales is caused by the agreements in the contracts. Unfortunately, this power has nowadays an unwanted effect, because it does not give the desired behaviour; the NS would like Thales to take the current needs of the traveller into account when making a planning to solve the incidents. However, according to the contracts which were established in 2003, Thales is only assessed on achieving the SLAs, so they do not look at the current needs of the traveller. However, trust is the biggest reason why the current collaboration is not going well. There is no trust towards each other and that is mainly because there is no transparency and understanding about each other's systems and processes, not from either the NS or Thales. At this moment the NS think that Thales does everything to make money, while it is also advantageous for Thales if a malfunction is solved quickly. For example, if there is more transparency about the incidents, one can learn more from the history of disruptions so that they can be resolved more efficiently for the future. That is why the solutions presented in Chapter 5.2 are often advantageous for all main actors, only they come from different requirements, see Chapter 4.

From the interviews with employees of both the NS and Thales (*No. 1, 14, 15, 18, 22, 25* and *27* see Table 1) it appears that power imbalances and especially trust issues in this case lead to a disrupted cooperation. The willingness to change behaviour appears to have no influence on this.

4. Requirements of key players

Now that the case study analysis has been performed in the previous chapter, as suggested in the methodological framework in Chapter 1.5, the objectives and constraints of the maintenance process of the station resources are examined in this chapter on the basis of requirement analysis. Subsequently, an answer can be given to sub-question 3. Furthermore, on the basis of the requirements, first the solutions for a more efficient maintenance process can be drawn in Chapter 5 and then the requirements can be used to evaluate the solutions in Chapter 6.

The requirement analysis for this research has been carried out according to the book System Engineering Fundamentals by the Defence Systems Management College (Systems Management College, 2001) combined with specific instructions from The Requirement Engineering Handbook (Young, 2004).

According to Young, a requirement is a statement that identifies a capability, characteristic, or quality factor of a system in order for it to have a value and utility for a user (Young, 2004). In the System Engineering Fundamentals (Systems Management College, 2001), it is added that Requirements relate directly to the performance characteristics of the system being designed. They are the stated life-cycle customer needs and objectives for the system, and they relate to how well the system will work in its intended environment (Systems Management College, 2001). In the same source, it is also stated that constraints are conditions that exist because of limitations imposed by external interfaces, project support, technology, or life cycle support systems. Constraints bound the development teams' design opportunities (Systems Management College, 2001).

The requirements for the maintenance of the station resources have been mapped by interviewing the experts, from both NS and Thales (see Table 1: *No. 1*, *18, 22 and 23*). These people have been interviewed because they have a good overview of the interests of the entire organization. Once the requirements were established, they were fed back to prevent misconceptions. In addition, some travellers were interviewed to get an understanding on the average conditions for "a pleasant trip" and how the unavailability of the station resources could impact their travel experience. These interviews took place in the train, because of this, feedback of the conclusions was not possible. However, they all confirmed each other's requirements, so it can be stated with reasonable certainty that no misconceptions have taken place.

For the purpose of this research, the requirements are listed according to the structure proposed by the System Engineering Fundamentals book (Systems Management College, 2001). Note that only the relevant categories of requirements for the scope of this research have been used.

4.1. Customer Requirements

This research is about limiting the nuisance for travellers caused by failures at station resources. A proper quantitative analysis is not feasible in the short timeframe of this research. Also the NS passenger satisfaction surveys do not cover the station resources part. In order to get some high level impression, a very exploratory research was done by interviewing 5 people on the importance of station resources requirements. This has no scientific value, but it gives a rough idea of the real situation. Two young people (23 and 27 years of age), both men, who were traveling for their studies, one man (57 year) who travelled for work, one woman (53 years) who made a train trip in her spare time and lastly also an older woman (83 years) who also made a leisure trip were interviewed in the train from Utrecht to Rotterdam on a Wednesday around 5 pm. With this a diversity of age, gender and trip purpose was questioned, which also covers the diversity within the passenger profile of the NS.

The most important outcome is that travellers want a pleasant trip without "nuisance". According to the interviewed travellers, "nuisance" can be caused by different things; train delays, crowds at stations, not being able to park your bike quickly at the railway station and nuisance due to station resources, the scope of this research.

Related to the station recourses, a nuisance can occur if people do not understand how the equipment works and – as a consequence – not able to purchase a ticket or checking in. In addition, a nuisance can also occur if there is too little equipment and travellers must walk far to a KVA or have to stand in line at a KVA, CiCo or gate. Travellers find it also important that railway stations are always safe and can easily process the flow of passengers. As an example, close to football stadiums, the direction of gates is adjusted to manage the huge flow of passengers. Last, all interviewed travellers unanimously concluded that an price increase should be avoided to reach the requirements. The following requirements were marked:

- Easy-to-use station resources
- Easily accessible station resources
- Enough number of resources
- Safe stations
- Station resources to respond to crowds during events
- No price increases of the train tickets

If the above requirements are met, nuisance can still occur because the station resources do not function, which can be caused by failures or preventive maintenance. However, not all failures and preventive maintenance will cause inconvenience, only if there are no other alternatives available within a reasonable distance. The following requirement can be derived:

- Need for sufficient "alternatives" at stations. If a station resource is out of order, another device should be available to handle the travellers request (check in / out or buy a ticket). This eliminates any nuisance

However, if no alternatives are present, a failure or preventive maintenance will cause inconvenience. This brings the following requirement:

- A quick dissolution time by the maintenance organization (Thales)
- Minimal impact during rush hours. Especially no inconvenience by failures or preventive maintenance when travellers are in a hurry

For the maintenance of the station resources, it is important to take these requirements into account. Because the travellers are one of the main actors for this research, but also both the NS and Thales want to give the traveller a nice trip without disturbances at the station resources, see Chapter 3.1.

Some travellers indicated that they also see periodic maintenance as a nuisance, because a resource is out or order for a while during planned maintenance. Periodic maintenance does, however, cause relatively less nuisance compared to reactive maintenance. This is due to the following two reasons: 1) the maintenance can be planned and can therefore take place outside rush hours. 2) The out of order time is shorter, because equipment is only out of order when the mechanic starts working and the work that the mechanic performs is always targeted maintenance. While the reactive maintenance process is started after the resource is out of order and then a mechanic goes to the location. Sometimes the schedule does not allow mechanics to go to the site immediately, so the device is out of service for much longer than just the mechanic's dissolution time. The root cause of a failure can also be unclear, so the work of the mechanic can take longer to find the solution.

Despite the fact that not all failures and maintenance cause nuisance for the traveller by definition, for this research it is assumed to be the case. Personal experiences can differ per person, the same goes for experiencing a nuisance or not. For example, one person finds it a nuisance when a KVA is broken even if there is an alternative next to it, while another traveller does not see this as a nuisance. Because of the limited timeframe of the research, no further research has been done into the nuisance for the traveller, but it is assumed that every failure or maintenance is a nuisance because one cannot use the desired resource item.

4.2. Functional Requirements

The necessary task, action or activity that must be accomplished (Young, 2004). This can be split in NS and Thales:

- NS - The availability (in function) of the station's resources. So that the traveller can easily use them without nuisance or danger.
- Thales - Solving the failures as quickly, properly and cost effective as possible.

4.3. Performance Requirements

The extent to which a mission or function must be executed; generally measured in terms of quantity, quality, coverage, timeliness or readiness (Young, 2004). This research focusses on the performance of the station resources. These must be in function for 99% of the time. If they are not in function, due to malfunctions, then the failure is resolved by Thales with reactive maintenance. The objective of reactive maintenance is to solve incidents and to restore the failed system to satisfactory operation within the shortest possible timeframe, the agreed KPI's (SLAs) and within the agreed cost level. A distinction is made between KVAs and OVCP equipment (gates, CiCos, LBS, information and alarm columns).

Reactive maintenance is performed on a demand-driven basis (DDM – Demand Driven Maintenance). This implies that incidents are solved with a priority that depends on the availability of the function of an object in a cluster of objects. The level of redundancy of objects in a cluster determines the level of DDM that can be reached. Two classification categories of incidents are distinguished (NS Groep N.V. & Thales Transportation Systems B.V., 2018):

- Fatal Incidents: immediately resulting in significant discomfort for the traveller
- Non-Fatal Incidents: not obstructing the traveller to perform a successful travel

The classification of an incident (Fatal/Non-Fatal) is done by NS and will be automated in the service maintenance tooling. The classification is done on a technical basis. For this technical basis, NS and Thales maintain a list of technical symptoms (incidents) with a predefined classification (Fatal/Non-Fatal) which is defined in a file with all agreements and procedures.

Based on the incidents that Thales receives from NS and the distinction between fatal and non-fatal failures, Service Level Agreements (SLAs) have been established by the NS within the incidents must be resolved, they are presented in Appendix 5 and the most important and most common SLAs are shown in Table 13.

Table 13, Service Levels Reactive Maintenance (NS Groep N.V. & Thales Transportation Systems B.V., 2018)

Description	Equipment	Service Level	Service Window	Conditions
After Acceptance of the call, solve the Fatal and Urgent incident	Ticket sales equipment, OVCP equipment: Gates, CiCos, NKZ, Emergency PLC/GEU units	95% < 4 hours	7 days a week 06.00-22.00	Within Area A *** Service window closed during rush hours*
			Working days 06.00-22.00	Within Area B*** Service window closed during rush hours*
			Weekend 09.00-17.00	Within Area B
After Acceptance of the call solve the Non-Fatal incident	Ticket sales equipment, OVCP equipment: Gates CiCos, NKZ, Emergency PLC/GEU units	95% < 72 hours**	7 days a week 06.00-22.00	Within Area A. Service window closed during rush hours *
			Working days 06.00-22.00	Within Area B. Service window closed during rush hours *
			Weekend 09.00-17.00	Within Area B

* Rush hours are applicable on working days from 07:00 – 09:00 and from 17:00-18:30. During the Rush hours, the Service window is closed on specific stations. These stations and the equipment involved will be listed in the DAP.
** The hours indicated have to be interpreted as un-interrupted 'clock' hours.
***The Service levels of the reactive maintenance are different depending on the geographic location of the assets under maintenance. To distinguish between Service levels for Geographic locations, two areas are defined; Area A and Area B. Locations are placed in Area A or in Area B based on the demand for maintenance on the assets in the corresponding Area.

Table 13 shows that for the resolution time a distinction is made between fatal and non-fatal faults. Fatal failures: 95% must be resolved within 4 hours within the service window. Non-fatal failures: 95% of the failures must be solved within 72 un-interrupted clock hours, so also outside the service windows. Different time arrangements apply for OVCP equipment glass repair, for gates, fixed barriers, doors and the repair of ramps because the glass must be replaced by a third party. However, it is the agreement that Thales arrives at a location within the SLA times to create a safe situation at the station resource. All these SLA agreements apply as KPIs for the service of Thales.

It is up to Thales how the schedule for the service window is organized; planning of shifts, the number of shifts, weekend shifts, standby shifts, etc. The SLAs defined for the service are leading in the performance of Thales.

Fatal incidents are planned based on the following planning criteria:

- Deadline
- Travel time
- Solving time

It is advantageous for Thales if a malfunction is not fatal due to the fact that they have more dissolving time, the work orders can be better and smarter planned. That is why agreements have been made about the ratio fatal versus non-fatal in the new contract in the new contract that has been in force since 2018. Until January -1st -2018, the Thales service organization was set up based on a ratio of 85% Fatal and 15% Non-Fatal incidents for OVCP equipment and a 90% Fatal and 10% Non-Fatal for Ticket Sales Equipment. As of January 1st, 2018 (since the new contract), Thales has set up its service organization based on a ratio of 60% Fatal and Urgent- resp. 40% non-Fatal and Fatal Not-Urgent incidents. This ratio is the subject of improvement in relation to the Demand Driven reactive Maintenance.

In addition to agreements on SLAs and the ratio of fatal and non-fatal failures, agreements have also been made about second visits. There are several conditions that the maintenance organization (Thales or a third party) must plan a second- and following visit to resolve an incident. For reasons outside the influence of Thales additional time is given for solving the incident.

The conditions for Second visits outside the influence of Thales are:

- Spare parts agreed not to be available in the car of the engineer
- The agreed number of spares on the car already consumed during the shift
- Request from NS to interrupt the incident recovery process
- Loading- and installation of Software takes longer than 30 minutes
- A required third party is not available for support
- The defective installation is unreachable (location closed, blocked, no access allowed, etc.)

When a second visit is needed to resolve the failure without one of the above reasons, Thales will not receive any extra solving time.

4.4. Derived requirements

Derived requirements are requirements that are implied or transformed from higher-level requirements (Young, 2004). For the NS and Thales, these are requirements arising from the functional and performance requirements.

For the NS, this means keeping the stations running as good as possible, against reasonable costs:

- Preventing failures:
  - Periodic and/or preventive maintenance
  - Monitoring and analyse failures
  - The purchase of good equipment

Most important for the NS are satisfied passengers. The fact is that failures cannot be prevented, derived requirements assure that passengers suffer as little as possible from a breakdown:

- The impact of a failure is as small as possible
  - Other station resources are available at stations, facilitating alternatives.
  - Suffering as few people as possible from the failure
  - Rapid repair of the station resource by Thales (good information about failure)
- Thales act on impact (if there is a fatal failure with a major impact, it should be given priority over a breakdown that has less impact)

For Thales, the functional requirement is that they solve the failures as quickly, properly and cost effective as possible. Efficient with a high as possible quality:

- Fast repair of the station resources
  - Short travel time
  - A mechanic can easily reach station resource
  - Enough spare parts in the vehicle of the mechanic

- Low costs - there are two different contracts, the TODI and the OVCP. With the TODI contract, Thales is paid every time they come to repair a ticket machine. Has he broken again the next day and another mechanic comes along for repair, they get paid again. With the OVCP contract, Thales receives a fixed amount of money for the maintenance of the gates and the CiCo's. The less Thales comes into action within this contract, the more earnings for Thales.
  - The first-time fix has to do with skilled mechanics and enough spare parts in the mechanic's vehicle
  - Monitor and analyse failures well. When a malfunction occurs more often, it is worth looking for a final solution instead of temporarily solving the malfunction again and again
  - Effective staff scheduling, to avoid having to work on "expensive" moments

Ultimately, Thales is keen on having the NS as a satisfied customer for all maintenance services. So low costs in the short term are not the most important, because it ultimately yields more money if the contract will be extended.

Conclusion

It can be concluded from this chapter that the interests and therefore the requirements of the main actors differ. Both the NS and Thales state that the greatest importance is the optimal functioning of the station resources causing least nuisance. Given the fact that both the NS and Thales are commercial companies with a profit and loss objective, they both have different interests. The main difference is that the NS wants to have the failure resolved as quickly as possible with the least impact for the travellers and as effectively as possible, while Thales wants the mechanics to do their work as efficiently and ultimately as effective as possible.

Sub-question 5 "*What are the requirements for the maintenance of station resources?* "of the research question was answered with this information.

From the customer-, performance- and functional requirements, categories are determined on which the designs in the next chapter, Chapter 5, will be evaluated. Using these categories, it can be concluded whether the solution directions for the inefficiencies (based on the current situation in Chapter 3) meet the requirements of the main actors.

If the customer-, performance- and functional requirements are met, the derived requirements are also automatically met, because derived requirements are requirements that are implied or transformed these higher-level requirements (Young, 2004).

Table 14 shows an overview of the requirements categories per main actor, followed by a brief explanation. Based on these categories, it is possible to evaluate the designs, presented in Chapter 5.2, on the difference in nuisance for the traveller and the difference in the equipment availability and maintenance costs for the NS. The categories for Thales keep an eye on how fast, good and cheap failures are resolved.

Table 14, Overview of the requirement categories

	Requirement Category	Topic from requirements	Explanation
Traveller	Customer experience	Nuisance	The impact of a disruption must be as low as possible for the traveller so that there is as little inconvenience as possible.
	Number of failures	Nuisance	The number of failures has a direct influence on the nuisance of the traveller. The less the better.
NS	Equipment availability	Availability	The NS measures the quality of the "product" in the availability of the equipment. This must be at least 99%.
	Dissolution time	Nuisance	In order to achieve the right availability, the NS want them to resolve malfunctions as quickly as possible.
	Number of (repeat)failures	Nuisance, costs	To limit nuisance for travellers and costs for NS itself, it is important that the number of (repeat) failures is as low as possible.
	Equipment costs	Costs	The better maintenance is performed and the service life of equipment can be predicted, the lower the equipment costs.
Thales	Dissolution time	Nuisance, Costs	The faster a failure is resolved, the less trouble the traveller experiences and the greater the chance that time is being traded within the SLA so that bonuses can be achieved.
	Staff, transportation costs	Costs	The more efficient the planning, the lower the personnel costs of mechanics, transport costs will be.
	Number of (repeat)failures	Nuisance, Costs	To limit nuisance for travellers and costs for Thales itself, it is important that the number of (repeat) failures is as low as possible.

Table 14 shows that some requirement categories of different actors correspond. In Chapter 7, the solutions proposed in Chapter 6 will be evaluated in a scorecard based on these categories: number of failures, number of repeat failures, equipment availability, dissolution time, transportation and staff costs, equipment costs, customer experience.

If the solutions have a positive influence on these categories and the requirements can be better achieved as a result, the maintenance and service of the station resources of the NS will ultimately improve.

5. Design of improvements

This chapter will look at solutions for the inefficiencies that arise from the literature research in relation to economic and maintenance studies and besides that, the experiences gained about the principal-agent collaboration between the NS and Thales during the research by means of interviews (*No. 1, 10, 12, 14, 15, 16, 19,21, 22* and *23* from Table 1), observations (*No. 15, 24, 25* and *27* from Table 1) and data analysis into the current maintenance strategy and the process.

Solutions are proposed to ultimately ensure that the maintenance process of the station resources is better aligned with the requirements of the main actors, see Chapter 4, making the process more efficient and therefore the service better.

In order to find solutions to inefficiencies, the most preferred situation for maintenance will first be examined in Chapter 5.1. Next, different improvements were presented in Chapter 5.2 to achieve part of the most preferred maintenance situation. A distinction will then be made between a short and long-term visions. Finally, Chapter 5.3 looks which solutions from Chapter 5.2 solve which inefficiencies from Chapter 3.

To formulate the preferred situation and the solutions to the inefficiencies in the current situation, assumptions must be made. First of all, the requirements, as set out in Chapter 4, remain the same. In addition, the technology in the equipment and the ease of use of the resources remains of the same quality or is even better. Finally, it is assumed that the equipment numbers and locations also remain the same. If this is not the case and there is less equipment, for example, the solution regions in which the mechanics work must be adjusted, which has a negative effect on the dissolution times. This is not included in the scenarios.

5.1. Most preferred maintenance situation

For the most preferred form of maintenance of station resources, the best scenario for the main actors is to have no failures, because that limits the inconvenience for the traveller. As Gassner (2009) indicated, reactive maintenance will always be needed because it is simply not possible to prevent all incidents. However, there is also an preferred procedure for the incident resolution process linked to station resources. The visual representation of this can be seen in Appendix 11.

When a failure occurs, it is desirable for the traveller that the inconvenience remains as small as possible. For this to work, the urgency of the failure must be considered and the maintenance process must be efficient. First of all, it is important that the incident information that the NS sends to Thales is correct and complete so that the planner can start using it immediately to draw up an efficient schedule, so that the qualifier does not have to be involved.

In addition, it is important that the mechanic can resolve the incident himself and that no additional WOT is needed because equipment parts in the vehicle or the skills of the mechanic are lacking. If Thales cannot solve the incident itself, the third party must show the best effort. If this is not achieved, another executing party will be hired. As a result, the dissolution time decreases, so that the traveller experiences less nuisance and Thales performs more efficient work, which will reduce costs.

It is preferable for the mechanic's solution time to be as short as possible, however, it is more important that he performs his work well, which might perhaps take a bit longer, instead of repeat failures occurring due to lack of care or hurrying.

It is important that a mechanic can work efficiently. He can only complete his incident response if everything is filled in correctly and completely so that no contact afterwards is needed between the NS and Thales. After that, the mechanic can immediately go to the next incident.

5.2. Improvements to reach the preferred maintenance situation

To come from the current maintenance situation to improvements, different scenarios have been drawn up with solutions, these are listed below per subject. The improvements were tested for feasibility by interviews with the executive people (*No. 7, 8, 9, 11, 12, 13, 14, 15 from the NS* and *24, 21, 25, 26, 27* from Thales in Table 1). An example of this in Chapter 5.2, is the proposal to remove a physical booklet containing notes about repairs. Both the mechanic at Thales, the people at the NS Operation Centre and product managers at the NS were checked (*No. 11, 12, 13, 15* and *24* from Table 1) to see if this was actually possible. This prevents solutions from being proposed that are not actually feasible.

5.2.1. Maintenance strategy

For the most preferred form of station resources maintenance, the best scenario for the main actors is if there are a few incidents as possible. This can be made possible by adapting the maintenance strategy from reactive to preventive maintenance in the short term, based on the use of the equipment. This is advantageous because preventive maintenance causes much less inconvenience to the traveller than reactive maintenance as it can be planned, allowing work to be performed outside rush hour or other undesirable moments. When planning is possible, Thales can also better take efficiency into account. Besides that, preventive maintenance costs money at first. Because research has to be done into the service life of different parts, it ultimately yields money, since the labour and transport costs will decrease. In the longer term, predictive maintenance is even cheaper and more efficient, since the lifespan of equipment can then be better determined, so that equipment costs will fall, which is advantageous for the NS because they are the owner of the equipment. In addition, predictive maintenance also makes it possible to detect faults before they actually happen. This means that fewer failures will occur compared to reactive or preventive maintenance. Thus causing less inconvenience to the traveller, and ultimately also benefiting Thales, because this type of maintenance can also be planned.

In this way, the ratio between preventive (or predictive- in the longer term) and reactive maintenance will change, but as already stated in Subchapter 5.1, reactive maintenance will always be needed because it is simply not possible to prevent all incidents.

5.2.2. Transparency within Service Now

To achieve the preferred maintenance situation, various solutions are possible within the current process. First of all, it is important that there is transparency in the information within Service Now. Preventive maintenance and reactive maintenance performed by Thales is already included in Service Now, but also the reboots that the NS carries out remotely and the maintenance by third parties, such as G4S, also count as maintenance and should therefore be part of Service Now. In this way Service Now can function better as a platform where information about all the maintenance of the station resources is displayed. As a result, analyses can be better done about repeat failures and equipment where many failures occur can be noticed earlier by focussing on CI numbers, which regularly break down. This can then be reported, by automatic notification from Service Now, to the Operation Centre at the NS, the service operator at Thales and the mechanic at Thales, so that they can adjust their solution strategy accordingly.

If there is more transparency in the disruptions, eventually better analyses can be made to prevent these disruptions in the future (through preventive and predictive maintenance), and this is one of the main goals of the NS and Thales. If there are fewer failures, the traveller is also less inconvenienced. In addition, more openness will also work better for the trust issues that arise from the principal-agent theory.

However, more data is not always better. It is important that one does not lose the overview and only uses data if it is useful and clear. For example, the information about a failure for the mechanic in the current situation, there is a lot of information displayed on his tablet or phone. There is no distinction though between main data and less important data as a result of which the mechanic does not look at everything and in some cases, useful information that was available does not reach the mechanic and is therefore lost. For example it may be that a mechanic does not look at the repair history, as a result of which a repeated failure occurs because the same repair work is carried out again, while it was known that it did not work. To prevent this, this type of important information should, when it matters, pop up on the phone or tablet as a notification. This can be done with an icon so that the technician knows that he must first delve into certain information before he starts working on the repair. Figure 20 shows some examples, one icon for repeated failures, an icon to indicate that the NS or Thales sends the mechanic additional information about the incident and a location icon that shows that the location of a resource does not contain a standard location, but, for example, a temporary one when there is work on a train route and a validator is placed at the place where NS buses stop. By default, all icons are dark, but when there is important information, the icon changes colour (see Figure 20) or pops up.

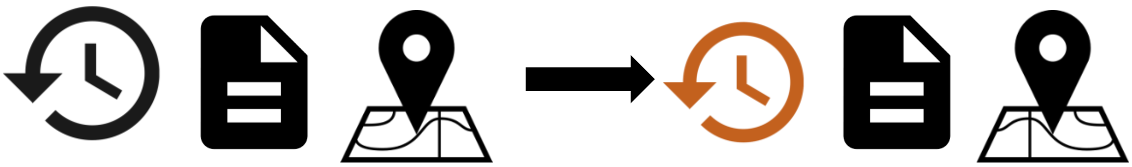

Figure 20, Examples of icons which makes important information more visible

5.2.3. Avoid unnecessary process steps NS operation Centre and the Service Operator at Thales

In addition, it is also important that the maintenance process runs efficiently. If the Thales qualifier has to do work because the incident information is not complete at the beginning of an incident, this causes unnecessary actions that take time. Sometimes this happens only on the side of Thales, when the qualifier can complete the incident itself, but sometimes contact must be made with the Operation Centre at the NS and therefore costs extra time for both actors. This does not benefit the dissolution time and therefore it does not benefit the traveller experience either.

One of the reasons for the contact mentioned in Chapter 3.2, was that the linked CI number from the NS to an incident is not known to Thales. This can be solved by checking the CMDB more often. The CMDB are two different databases (one from the NS and one from Thales) that occasionally do not match, due to new or moved equipment or equipment that is not in maintenance with Thales. By checking the database more often items that do not match can be prevented in both databases. However, a function can also be built into Service Now, which checks when a CI number is entered, whether it is known in the Thales CMBD. If this is not the case, it should not be possible to send an incident to Thales. First, the problem must be solved for the different or unknown CI numbers. Unless there is no information available about the actual malfunction, it is beneficial to send a technician on the road, so that someone on site can see what the incident is causing and a suitable solution can be found.

In addition, it may also occur that additional contact between the NS and Thales is needed due to other templates than normal that are used or that something deviates in the title or something is unclear about an incident that the NS sends to Thales, then the incident will automatically end up at the qualifier. To prevent this, it is important that everyone speaks the same language, in other words, creates the same templates in Service Now. Besides that, it always needs to be clear what is meant by extra comments from the Operation Centre at the NS. Rather use some extra words for clearer explanation than that misunderstandings arises due to inadequate or unclear information.

This also applies to the incident of the candy machine, which was used in Chapter 3.2 to indicate an example of an incident that was eventually cancelled. This should never have ended up as an incident at Thales because the Operation Centre should have asked more about what kind of equipment the failure was about so that this type of miscommunication can be captured. The quality of the information is of great importance to keep the maintenance process efficient.

5.2.4. Demand -Driven failure prioritisation.

Subsequently, when an incident is created, demand-driven failure prioritisation has to be taken in the most preferred situation. For this purpose, the station resource itself and the urgency that a failure causes will be looked at, in addition to looking at the actual fault that takes place.

5.2.4.1. Urgency

The current process only looks at the actual fault that takes place, but this does not take into account what kind of environment and equipment item fails. However, it would benefit the traveller if the urgency of a failure is also considered. This means that one must look at four things in the short term. 1) other alternatives in a zone. Is there a KVA nearby or are there other gates available where one can also check in if initial gate is out of order? If so, the urgency is lower than when that is not the case. This must be determined per zone, because at a large station like Utrecht Central, if all KVAs are broken on the city centre side, but on the other hand they all function on the Jaarbeurs side, this does not count as the same zone and travellers will still experience a lot of inconvenience, because it is not "easy" to go to another alternative at this station. 2) safety, when unsafe situations arise due to incidents because there are not enough gates functioning for the number of travellers, the urgency is high. 3) type of equipment item that is broken. If this is a wide gate that people with a wheelchair have to use and there is usually only one in a row of gates, then this has a higher urgency than a normal gate failure. A wide gate counts as a normal gate, but a normal gate is not a wide gate when looking at alternatives for point 1. 4) Change of normal situation. When a large event takes place at a certain location, such as King's Day in Amsterdam or the International Four Days Marches Nijmegen event, many more people are expected than usual. As a result, it is of greater importance that all the equipment is available, so there is a higher urgency if a malfunction occurs at the time of the event than in the normal situation.

In the long term, it is also more beneficial for the traveller to take future passenger flows into account when determining the urgency. This can be determined on the basis of historical data and when a failure occurs and a large flow of travellers is expected, a rapid resolution is preferable to an incident that happens at a resource that will hardly be used. The peak load on equipment should take precedence. However, this is something for the long term, because if this is implemented, the solution period (SLA) must also become flexible. However, it is firstly important that planning maintenance based on the above 3 points (alternatives, safety, item type of equipment) works well before it becomes even more complex.

5.2.4.2. Actual failure

In addition to the urgency, to make the planning in the preferred situation, the actual fault must also be considered. It is advantageous for Thales if the ratio between fatal versus not fatal changes, because when there are fewer fatal failures and more non-fatal failures, compared to the current situation, Thales has more time to resolve incidents. It gives them more flexibility to make efficient planning. However, the ratio between fatal and non-fatal failures cannot just change, so the concept, explained in Chapter 4, needs to be adjusted. Perhaps there can be a middle category, where a component is fatal, but the main function can still be performed. An example of this is a KVA, if cash cannot be used for payment, the disruption in the current situation is fatal. However, debit cards can still be used, so a valid ticket can still be purchased. The malfunction is therefore not fatal but has degraded functionality. The status of a device can then be:

- Nothing wrong, works properly
- Minor failure (in the current situation: non-fatal)
- Degraded functionality
- Fatal failure

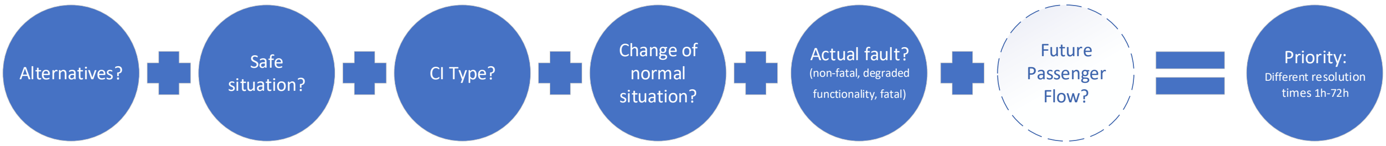

Figure 21, Overview of components that determine the priority of the failure

The presence of alternatives, required safety, the item type of the equipment, the presence of an event and the actual fault subsequently determine the priority that a failure will receive and upon which a resolution time for Thales and the SLAs can be determined. The SLAs will have to be adjusted from only the fatal versus non-fatal option to multiple options, so that Thales can act better with regard to the various priorities of the incidents. An example of this is given in Figure 22.

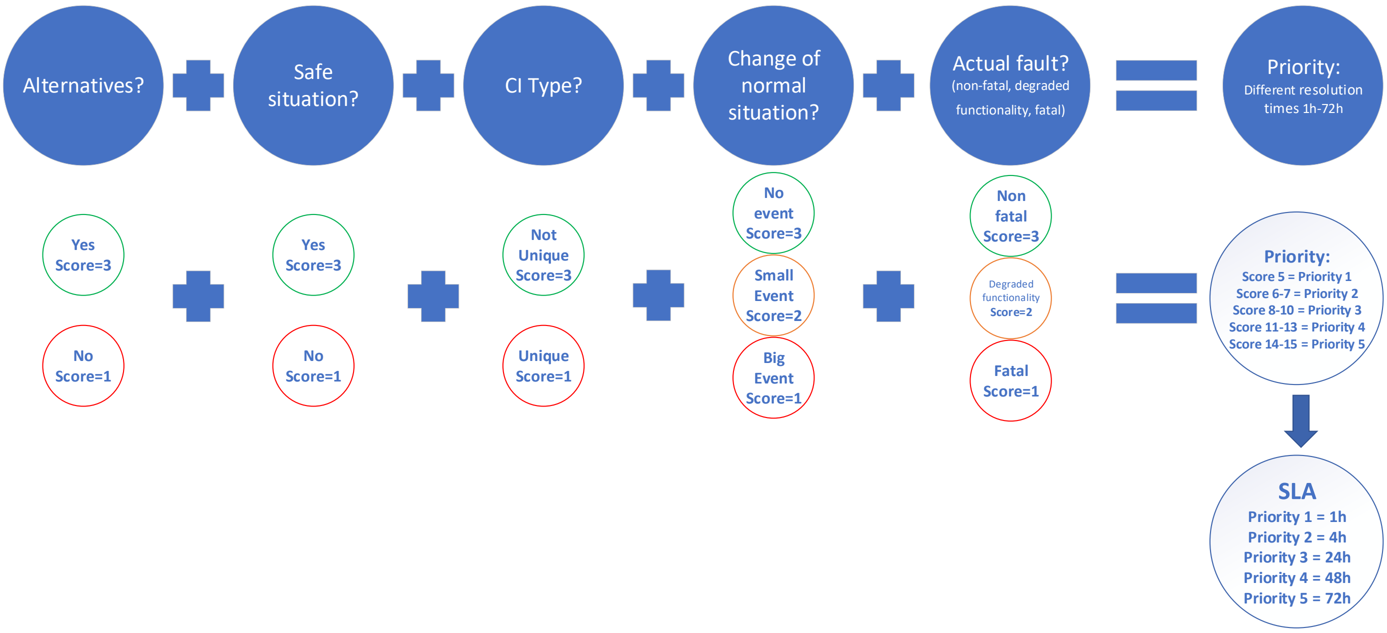

Figure 22, Example of possible prioritization of an incident

In this example, a score is given to each category. If a failure within a category ensures that the traveller would like it if a mechanic comes to the site sooner, then it gets a low score. For example, if there are no alternative resources nearby, if there is no safe situation, a wide gate is interfering, a major event is taking place near a station and a failure is fatal. If it is less urgent, the category gets a score of 2 or 3. All scores are then added and the priority is determined on the basis of this. If a fault has priority 1, it must be resolved within 1 hour and if it has priority 5 within 72 hours.

It must be said that this is a simplistic example. There is probably a different weighting between each category. Because a traveller may find it more important that there are alternatives that still function, than checking for the CI type. In addition, there will probably also be more diversity in the scores within a category. Now it is only assumed that the category consists of alternatives or not. But for a more realistic picture, an additional distinction may have to be made about if there are alternatives, if they are also within the same zone. Figure 22 only gives an impression about a possible future scenario where different categories provide different scores, which are a priority of an incident. To which an SLA is subsequently attached to resolve the incident.

The changing SLAs now achieve that both the urgency of the prioritization is taken into account, but also that there is a broader resolution time for incidents with a low priority (4 and 5), so that Thales can organize maintenance more efficiently.

5.2.5. Efficient planning by Thales

The Thales planner must take this prioritization into account in order to achieve the SLAs, but there are also other things that he must take into account in order to keep the planning as efficient as possible for Thales itself, but also for the traveller. Because in addition to the location and the associated travel time for the mechanic, it is important that in addition to the NS operation centre, the Thales planner is also alert to repeat failures. Besides that, he must also be alert to failures that can be combined and for which, for example, more equipment is needed than there is in the mechanics' car. It is then advantageous to first drive past the warehouse, pick up extra parts, so that one mechanic can solve three similar malfunctions, instead of having 3 different mechanics on site. This saves on staff and travel costs for Thales and therefore also solution time for travellers.

In addition to being alert to repeated and possibly combined faults, it is also important that equipment in the vehicle of the mechanic is kept up to date. Because it is possible that the equipment numbers in the vehicles have to be adjusted (both by NS at the TODI equipment and by Thales at OVCP equipment). For example, it may be that due to a certain age of equipment, parts break down much more often than before. The equipment stock must then be adjusted to prevent mechanics from arriving on site and a new WOT is needed, as it appears that the required parts were not present in the vehicle.

To make planning even more efficient, it would be advantageous for mechanics to work overarching with the various transport companies, such as Ziggo technicians work in Appendix 3. Mechanics are then not only suitable for deployment to NS failures, but also for the GVB or HTM and vice versa. However, it must be said that the equipment is different per transport company, so a gate of the NS is not the same in terms of equipment as a gate of the GVB. The mechanic training can therefore be chosen so that every mechanic can solve all the equipment of all transport companies, but many skills are expected from starting mechanics, which entails a risk in terms of lack of skills and therefore more WOT per incident and that was not desirable in the preferred situation. That is why Thales can also opt for a pyramid shape for the organization of the training of mechanics. The pyramid shape can be based on the number of disruptions per equipment type at all transport companies that are a customer of Thales. For example, if gates cause the most incidents, the training of mechanics starts to solve all type of gates from all customers. They then learn to solve an equipment item that is less likely to disturb, etc.. The more experience a mechanic has, the more equipment types a mechanic can solve, so it will occur less often that a mechanic does not have the right skills.

This ensures that the failure can be solved more efficiently by the right mechanic and that fewer WOTs are required per incident. In addition, it is advantageous for the solution- and travel time when a mechanic can repair equipment from several transport companies. A mechanic who has solved a failure at Amsterdam Central for the GVB can then also repair a failure for the NS. This saves a lot of travel time so that the failure is resolved faster. Advantageous for both Thales and the traveller.

However, this solution only applies to solution areas where there are several Thales customers. In the north of the country, for example, a technician does not have to be able to solve GVB equipment, because he will never encounter it during his work.

5.2.6.Scorecard third party

Due to the aforementioned improvements on the planning and organization of the mechanics at Thales, an incident would only need one WOT, which is also desirable in the preferred maintenance process. However, it is still possible that Thales needs a third party for the solution of the incident. This party is expected to act as quickly and as well as possible. It is therefore important that Thales keeps track of the performance, so that if the results are not satisfactory, they can switch to a different solution party. This can be done with a scorecard with, for example, SLAs about the resolution times of various incidents. Good results are rewarded by bonuses and bad results by maluses since a financial incentive usually works with commercial companies.

5.2.7.Scorecard Thales mechanics

The priority and related SLAs for an incident are for achieving the desired behaviour by the NS at Thales. It is therefore important that the solution time of the mechanic is as short as possible, however, it is more important that he performs his work well, which perhaps takes a bit longer, than repeat failures occur due to lack of care or hurry. It is therefore important that, in addition to monitoring the performance of third parties, Thales also looks at the performance of their mechanics. This can also be done by means of a scorecard that keeps track of the resolution times of incidents of a mechanic, but especially how often there is a repeat failure after the work of a particular mechanic. If the results are disappointing, a mechanic must be approached for this, with the aim that he will do his job better and, in particular, prevent repeated failures. This may also include a bonus/malus regulation, which gives mechanics an extra financial incentive to do their job well. This may cost Thales more salary costs, but it also ensures that there are fewer (repeat) disruptions, which ultimately results in money.

It is not possible that mechanics only choose easy malfunctions so that they achieve good results, because the malfunctions are assigned to mechanics by the planner. The planner does take the skills into account, so it may be that a mechanic with more experience has difficult failures, but he is also in a higher salary scale than a starting mechanic.

5.2.8.Avoid duplicate / unnecessary process steps for the mechanic

In addition to having a mechanic work properly, it is also important that he can perform his work efficiently. For this, it is important that he does not have to go through repeated processes. For example, after resolving the incident, he will only have to enter all data in Service Now and no longer in the physical booklet. In addition, the mechanic no longer always has to call the NS to close an incident. This only needs to be done when a pin terminal fails, because a mechanic cannot see the status of it due to privacy restrictions, but for the rest of the equipment, the mechanic can see for himself whether the failure has been resolved or not.

Besides that, a mechanic can only close an incident if he has entered all information correctly and completely. As a result, contact with the NS and Thales is no longer necessary afterwards, because the information was incomplete. After the mechanic has entered all the information about his work in Service Now, he can in the preferred situation immediately proceed to the next incident. Alternatively, if he has time left until he has to go to the next incident, he can perform preventive maintenance, as suggested in Appendix 3 with the example of the ATMs by Tomaney (2016).

This efficiency ensures a faster process, so a quick dissolution time, so that the traveller experiences less nuisance. But in addition, the Operation Centre at the NS now has fewer phone calls, leaving them more time for other matters such as monitoring and analysing malfunctions as Tomaney (2016) suggested in Appendix 3 with the example of the ATMs.

5.2.9. Contract type

In addition to improving the efficiency of the process through more efficient solutions, the type of contact between NS and Thales also helps. A contract forces parties to work in a certain way. Chapter 4 explains that there are now different contracts, namely the OVCP and TODI contract, both with a different incentive. For the preferred situation, it is best for the NS if all the equipment falls under one full-service contract. According to the theory, this should cause the right incentive, because everything that Thales tackles more efficiently (which is often more efficient for the traveller) will immediately generate money for them. However, the NS must not have the feeling that they are paying too much. But this will already be better, due to the experience that is now available with the station resources.

Within this full-service contract, the inefficiency of software releases should also be resolved. Because in the current process, Thales is not settled by means of a financial malus for the many disruptions that occur after a software release, because the SLA is then temporarily suspended. However, with a new full-service contract, Thales is responsible for maintenance and software updates. And when this happens within the SLAs they will receive a bonus from the NS and when this does not happen within the SLAs they will get a malus.

Now that this financial incentive applies to all equipment and there are no exceptions, it is likely that Thales will be more driven to work more efficiently because it generates money. This also means that it is logical for them to carry out their own research into preventive and predictive maintenance, as this ensures that Thales can perform its work more efficiently because the incidents with this maintenance strategy will decrease and people work more according to planned maintenance than reactive maintenance.

5.3. Analysis of the improvements

In Chapter 5.2 the following sixteen, in no particular order, proposals were made for improvements to the current process to move towards the preferred maintenance situation, which is presented in Chapter 5.1;

1. Preventive maintenance
2. Predictive maintenance
3. Update CMDB more often or CI number check
4. If the information is transferred or added manually, it is always complete and clear
5. Service Now Transparency
6. Demand-driven Maintenance - urgency
7. Demand-driven Maintenance – actual failure
8. Planner Thales alert to repeat and combined failures
9. Periodically revised equipment in vehicle mechanic
10. Mechanics PTO independent
11. Scorecard third parties Thales
12. Scorecard mechanics
13. Avoid repeated process steps – no physical booklet
14. Avoid repeated process steps – Less phone contact NS and mechanic
15. Avoid repeated process steps – mechanic can only close incident when complete
16. Full-service contract type for all resources

Table 15 shows which solutions solve or improve which inefficiency from Chapter 3, indicated by an X. Which is important to know, because in this way it is possible to determine whether all inefficiencies resulting from the case study analysis in Chapter 3, are addressed by the solutions from Chapter5.2.

Table 15, Overview which solution solves which inefficiency

Inefficiencies /Solutions	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Undesirable behaviour due to the permanent contract European tender while the desired situation was unknown																X
Unnecessary contact and work because malfunctions are reported by Thales, but they are not the solution			X	X												
Undesirable behaviour due to different classification of incidents NS and Thales						X	X									
Unnecessary contact and work because incident information is not complete at the beginning of or after resolving the incident			X	X											X	
The mechanic not correct and not useful use of failure information.					X											
The occurrence of multiple WOTs per incident									X	X						
No efficient work planning for Thales caused by: maintenance strategy, the amount of fatal vs non-fatal failures and PTO specific mechanics	X	X						X	X	X	X					
Unnecessary contact and work caused by telephone contact mechanic and NS after resolving incident														X		
Unnecessary work by the mechanic because work notation needs to be both in Service now and physical booklet													X			
Unnecessary amount of failures and work due to repeat disruptions					X			X				X				
Unnecessary amount of disruptions and work due to software releases																X

As can be seen, it can be concluded from Table 15 that all inefficiencies are addressed with the 16 solutions. Some solutions affect multiple inefficiencies like, for example, “solution 16 - Full-service contract type for all resources” affects the inefficiencies created by contracts from the European tender and the inefficiencies due to software releases. In addition, some inefficiencies benefit from multiple solutions, such as the inefficiency of multiple WOTs per incident, this is improved by “solution 9- Periodically revised equipment in vehicle mechanic”, because the equipment in the vehicle of the mechanic now better meets the need and “solution 10 - Mechanics PTO independent”, because they now have better skills and the chance that they can resolve an incident at once is bigger.

Now that is known that the proposed solutions address the inefficiencies, it is essential to determine which solutions are the most important to implement first. That is why the solutions in Chapter 6 are evaluated on the basis of the requirements from Chapter 4. Because the better they meet the requirements of the main actors, the better the maintenance and service of the station resources of the NS will ultimately improve.

Conclusion

When developing the solutions, inefficiencies resulted from the wrong maintenance strategy, double processes and inattentions of staff, were taken into account. In addition, there is also looked at how the trust issue from the principal agent collaboration between the NS and Thales could be improved. The most important step to achieve this is transparency within Service Now, but also in other data. Nowadays, as mentioned earlier in the introduction in Chapter 1.1, smart data can be created on the basis of sensors in equipment and the IoT, from which many benefits can be gained. Advantages are, for example, the earlier detection of malfunctions and the prevention of repetitive malfunctions.

The NS expects Thales to resolve malfunctions as quickly as possible and Thales wants to do this as efficiently as possible so that the costs are as low as possible. This requires transparency of data, so Thales can apply a more efficient maintenance approach with the smart data about failures.

However, in the current situation, Thales only knows something about preventive maintenance and reactive maintenance performed by itself. They know nothing about the reactive maintenance that the NS performs and the use of the resources. The NS occasionally provide an update on this, but that does not promote the desired behaviour. So if there is more transparency, Thales could apply a better approach to the maintenance, and this will ensure that NS gains more confidence in the service that Thales offers.

Of course, there are always trust issues because Thales will never make known what their earnings model looks like. But in the end, it is about the NS trusting Thales to provide the best and most efficient service possible. If this is the case, and is seen by the requirements of both the passenger and the NS, the NS will have no qualms paying a reasonable price for this service.

In summary, if Thales shows that they want to improve the maintenance strategy and processes, so that the requirements of the main actors can be better achieved, the NS will have more confidence in the service that Thales offers. This will subsequently increase the trust between both parties. The most important way to achieve this is more transparency in the data, so that smart data can be made of it and it can be learned from previous disruptions so that they can be prevented in the future.

6. Evaluation of improvements

This chapter examines whether the solutions proposed in Chapter 5.2 for the maintenance of station resources meet the requirements of the main actors. This is done in Chapter 6.1 on the basis of a scorecard. Subsequently in Chapter 6.2, after a discussion with the experts of the NS and Thales (see Table 1: *No. 1, 18, 22 and 23*) conceptual changes for the current system in response to the solutions have been drawn up and proposals are made which solutions should be applied first.

6.1. Scorecard

This subchapter examines how the solutions meet the requirements of Chapter 4. This is important because it can be seen from the requirements whether the solutions are an advantage for the main actors or not. Table 16 provides this overview. The various solutions are listed in the rows and the requirement KPIs of the travellers, the NS and Thales in the columns. "0" indicates that nothing changes compared to the current maintenance situation, and "+" or "++" indicates that a solution has a positive effect on the requirements of one or more actors and "-" indicates that the solution has a negative effect. The most striking results, circled with a red circle will be explained below the table.

Table 16, Score chart solutions

		# failures	# repeat failures	Equipment availability	Dissolution Time	Transportation and Staff Costs	Equipment Costs	Customer experience
1	Preventive maintenance	+	0	+	+	++	+	+
2	Predictive maintenance	+	0	+	+	++	++	+
3	Update CMDB more often or CI number check	0	0	+	+	+	0	+
4	If information is transferred or added manually, it is always complete and clear	0	0	+	+	+	0	+
5	Service Now Transparency	+	++	+	+	+	0	+
6	Demand-driven failure prioritisation - urgency	0	0	-	+ and -	-	0	++
7	Demand-driven failure prioritisation – actual failure	0	0	-	-	+	0	-
8	Planner Thales alert to repeat and combined failures	+	++	+	+	+	0	+
9	Periodically revised equipment in vehicle mechanic	0	0	+	+	+	0	+
10	Mechanics PTO independent	0	0	+	+	+	0	+
11	Score card third parties Thales	0	0	+	+	-	0	+
12	Score card mechanics	+	+	+	+	-	0	+
13	Avoid repeated process steps – no physical booklet	0	0	+	+	+	0	+
14	Avoid repeated process steps – less phone contact NS and mechanic	0	0	+	+	+	0	+
15	Avoid repeated process steps – mechanic can only close incident when complete	0	0	0	0	+	0	+
16	Full service contract type for all resources	+	+	+	+	+	+	+

The scores are based on the knowledge gained during the study and the expected results. They were then fed back to the NS and Thales experts (see Table 1: *No. 1*, *18, 22 and 23*) to check whether the correct conclusions were drawn. Some assumptions have been adjusted on the basis of a discussion with these experts and the final result can be seen in Table 16.

A general remark to understand the meaning of the "+" and the "-" in the table, is that a solution gives a positive effect if the number of (repeat) failures decreases, the equipment availability increases, the dissolution time decreases, the transport and staff costs decrease, the equipment costs decrease and the customer experience increases. All this causes less inconvenience to the traveller or fewer costs for the NS and/or Thales. Furthermore, a single "+" or "-" indicates a positive or negative effect, while "++" indicates that the relevant solution has much more impact on the specific requirement. For example, the customer experience improves in most solutions so a "+", but the solution "demand-driven maintenance – urgency", is mostly focused on the needs of the customer, so this solution will have an even more positive effect in comparison with the other solutions, hence the "++".

A detailed explanation of the interpretation of Table 16 can be found in Appendix 12 and the most striking results, circled with a red circle will be presented here. First of all, the equipment costs will be the lowest at the solution where predictive maintenance has been proposed. This is because smart data can be used to accurately determine when equipment will break down, so the component will be replaced at that precise moment. This makes the service life as effectively as possible, which is advantageous for the NS because the equipment belongs to them. With this maintenance strategy, the economic optimum for carrying out the amount of maintenance versus the costs is best achieved.

After that, the solutions about more transparency within Service Now and a planner of Thales who is more alert will cause fewer repeat failures and prevents malfunctions from not being combined while this could have been done. Preventing repeat failures and combining malfunctions is advantageous for the traveller because they experience less inconvenience. But this is also advantageous for Thales because they can save on transport and personnel costs because ultimately a mechanic has to take less action, as a result of fewer disruptions. This is especially advantageous if Thales has a full-service contract because money saved is turned directly into profit.

In addition, an alternative maintenance strategy ensures that more planned maintenance takes place in relation to reactive maintenance. This is very advantageous for Thales in terms of costs, as they can drive efficient routes and perform work when it suits them. In addition, planned maintenance also causes less inconvenience compared to reactive maintenance for travellers, which is also positive for the customer experience.

When the demand-driven maintenance is considered, the solution that takes into account the urgency has a very positive effect for the traveller and therefore also for the NS. The resolution time may turn out to be more positive when a failure is very urgent. On the other hand, if a failure is not urgent, the resolution time will be longer than in the current situation. The same goes for situations where the demand-driven maintenance looks at the actual failure. Within this solution, a proposal is made to ensure that fewer failures are labelled as fatal. Because then the SLA has wider resolution times for maintenance, which is good for Thales's efficiency. The resolution time can be longer though than in the current situation, which leads to a decline of equipment availability and a negative impact on the customer experience.

So the solution on demand-driven maintenance that takes the urgency of a failure into account, is advantageous for the traveller and the NS. The solution about demand-driven maintenance, where actual failure is taken into account, is especially beneficial for Thales. That is why the solution proposed in Chapter 5.2 suggests that these solutions have to be combined in order for all three main actors to experience benefits. Thales receiving relatively less fatal disruptions, leading to more efficient planning. Subsequently they need to align their priority in line with high urgencies. Which – in the end - is advantageous for the traveller and therefore also for the NS.

Finally, the minuses at the transportation and staff costs are noteworthy at solution 11 and 12. These are negative because, the incentive structure the bonuses and maluses, can cost Thales extra money if the third party and the mechanics do their job well. However, this is not by definition a negative effect for Thales, because the desired behaviour has been achieved due to the fact that the faults are resolved faster and better. Consequently, Thales will receive a bonus and the confidence of the NS in the service of Thales will be positively impacted. In the end, the costs increase on personnel costs for Thales will be balanced out.

6.2. Discussing the solutions

6.2.1.Conceptual changes in response to the solutions

At this moment, the quality of the equipment and the service are assessed on the basis of the equipment availability. This must be at least 99%. When considering the current needs of the traveller, a new concept – named customer experience - must be introduced. This concept is concentrated on the level of nuisance the traveller is actually experiencing.

By acting according to the urgency of a malfunction, the availability of equipment may deteriorate. As an example, if a gate at a big station in a row of 20 alternatives causes a malfunction and the urgency aspect is taken into account, this gate may be out of order for a week. Because it does not cause any inconvenience due to the fact that there are enough alternatives to ensure the flow and safety of travellers. The availability of equipment decreases as a result, however, the customer experience increases because repairs are planned according to what has the most impact for the traveller. Disruptions that cause the most inconvenience will be resolved more quickly compared to the current situation.

The concepts of equipment availability and customer experience must therefore be viewed separately. With regard to the preferred situation, it is especially important that the customer experience is high. Slight decrease of the equipment availability, as a result of higher customer experience, will have limited negative side effects. Ultimately it is about what ensures the traveller to have a pleasant journey and how station resources contribute to a good customer experience.

6.2.2.Implementation of the solutions as a result of the evaluation

Table 15 has shown that all inefficiencies are addressed by the proposed solutions and from Table 16 it can be concluded that all solutions have a positive influence on the customer experience Table 15. However, not all solutions can be implemented at once, that is why implementation priorities are drawn upon the basis of various criteria and in consultation with experts from the NS and Thales (see Table 1: *No. 1* and *22)*.

Setting the priority of implementation is determined on the basis of 1)improvements in economic relevance, so that the economic optimum is better achieved, 2)improving trust issues in the principal-agent cooperation, so the customer experience gets better, 3) the reach of the solution, or, does the solution has any effect on every failure or only occasionally. And lastly, 4) the probability that the solutions will actually achieve the desired effect.

These criteria were chosen based on the literature from Chapter 2. Also the research in this case study, has shown that the economic relevance of a process is always important. In addition, this study shows that collaboration is an essential factor, which can deteriorate efficiency. A key driver for both NS and

Thales would be that solutions will actually better achieve the requirements from all actors. Solutions therefore need to have a large reach. When inefficiencies occur with every failure and can be remedied by improvement, this has a significant better effect than resolving an inefficiency that occurs sporadically. If a solutions desired effect is not certain, it will not be given priority for implementation.

Table 16 from Chapter 6.1 is shown again below, the content has remained the same, this time the criteria for setting the implementation priorities are highlighted in Table 17.

Table 17, Score card solutions - implementation priority

		# failures	# repeat failures	Equipment availability	Dissolution Time	Transportation and Staff Costs	Equipment Costs	Customer experience	
1	Preventive maintenance	+	0	+	+	++	+	+	+7
2	Predictive maintenance	+	0	+	+	++	++	+	+8
3	Update CMDB more often or CI number check	0	0	+	+	+	0	+	+4
4	If information is transferred or added manually, it is always complete and clear	0	0	+	+	+	0	+	+4
5	Service Now Transparency	+	++	+	+	+	0	+	+7
6	Demand-driven failure prioritisation - urgency	0	0	-	+ and -	-	0	++	+3
7	Demand-driven failure prioritisation – actual failure	0	0	-	-	+	0	-	+1
8	Planner Thales alert to repeat and combined failures	+	++	+	+	+	0	+	+6
9	Periodically revised equipment in vehicle mechanic	0	0	+	+	+	0	+	+4
10	Mechanics PTO independent	0	0	+	+	+	0	+	+4
11	Score card third parties Thales	0	0	+	+	-	0	+	+3
12	Score card mechanics	+	+	+	+	-	0	+	+3
13	Avoid repeated process steps – no physical booklet	0	0	+	+	+	0	+	+4
14	Avoid repeated process steps – less phone contact NS and mechanic	0	0	+	+	+	0	+	+4
15	Avoid repeated process steps – mechanic can only close incident when complete	0	0	0	0	+	0	+	+2
16	Full service contract type for all resources	+	+	+	+	+	+	+	+7

Table 17 shows how the implementation priority was determined on the basis of the 4 criteria mentioned (improvements in economic relevance, improving trust issues, the reach of the solution, and the probability that the solutions will actually achieve the desired effect). The assessment explanation thereof is described below.

1) The economic relevance has been tested on the basis of better efficiency. If the process goes better, there will be less waste and the economic optimum is better achieved. This has been

tested by adding using the "+" and "++" of every solution in the table. The solutions with the highest scores are interesting for this assessment criterion and are shown in the most right hand column, arrow 1. This shows that adjusting the maintenance strategy would be the best solution for economic relevance. This corresponds to the findings in the literature, Chapter 2.3.

2) Trust issues between NS and Thales are best resolved, in this case study, if the customer experience is good. This has proven to be the best with solution 6, Demand-Driven failure prioritisation, arrow 2.
3) The reach of each solution differs. In the second column, at arrow 3, it is indicated in an orange colour which solutions affect every failure, these are solutions 6, 7, 13 and 14. When these solutions are implemented, the improvement is noticeable with every failure.
4) The probability that the solutions will actually achieve the desired effect is difficult to say with certainty. But in discussions with the experts from the NS and Thales (see Table 1: *No. 1* and *22)* and knowledge gained from the research that has been carried out, it has been determined that more transparency in data in several areas will ensure a lot of efficiencies. Repeat failures can be prevented in this way, but better research for periodic maintenance can also be done if more smart data is available.

It can be concluded that the solutions with the red circles in Table 17 are the solutions that best meet the four implementation criteria. Some solutions are combined because they together form a solution direction. Solution 1 "Preventive maintenance" and solution 2 "Predictive maintenance" together form the solution direction for “The right maintenance strategy” for the station resources. Solution 6 "Demand-driven failure prioritization - urgency" and solution 7 "Demand-driven failure prioritization - actual failure" together form the solution direction “Demand-driven failure prioritization” and as last forms solution 13 "Avoid repeated process steps - no physical booklet" and solution 14 "Avoid repeated process steps - less phone contact NS and mechanic" together the solution direction to prevent, so “No unnecessary procedures and processes”. “Transparency” is also a solution direction, it comes from solution 5 "Service Now Transparency". These four solution directions will ensure that the requirements of the main actors are achieved better, so that the maintenance and service of the station resources of the NS will ultimately improve.

Figure 23 below shows how these solutions contribute to better economic relevance and customer experience. General solution directions have been made of the concrete solutions from Table 17 according to the case study, as a result of which Figure 23 can also be applied in other maintenance fields. These general solution directions are: Demand-driven failure prioritisation, transparency, no unnecessary procedures and processes and the right maintenance strategy.

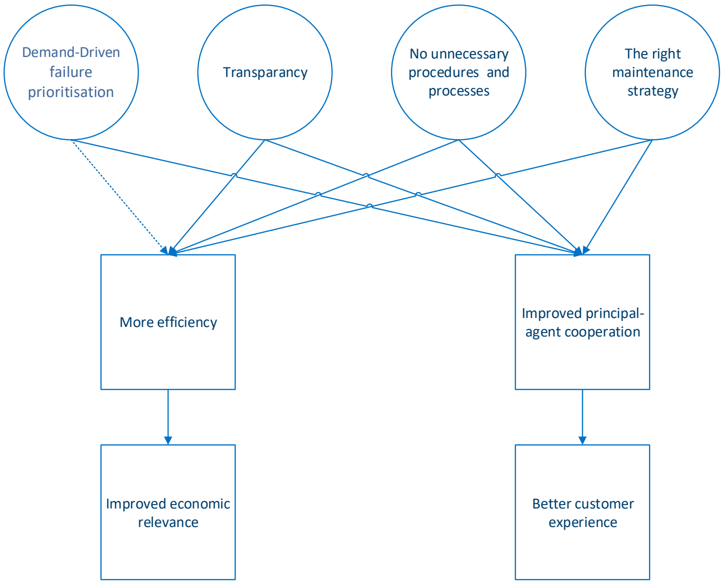

Figure 23, Concluded relation between scientific concepts

Figure 23 shows, how the solution directions in the circles contribute to more efficiency in the process and an improved principal-agent cooperation. More efficiency in the maintenance process will ensure that the economic optimum is increasingly achieved and a better principal agent cooperation will lead to less trust issues and thereby a better customer experience.

Demand-driven failure prioritisation has a dotted line connection with "more efficiency". Larger SLAs slots will ensure more dissolution time, so Thales can plan better and more efficient. However, this solution is primarily focused on the customer experience, so the process efficiency improvements will be limited compared to other solutions.

As mentioned earlier, the rest of the solutions proposed in this research also have a positive effect on process efficiency and therefore most of the time also contribute to the customer experience. However, these solutions contribute less to the 4 prioritization criteria mentioned, and therefore have a lower priority than the solutions mentioned in Figure 23. As an example solution 3, the inefficiency that arises because the CMDB is not up-to-date, does not occur every failure. The introduction of solution 3 therefore has less effect than the introduction of, for example, Demand-Driven failure prioritisation, which will have an impact on every failure. The solutions highlighted in Figure 23 will most certainty deliver much economic relevance and a better customer experience. For other solutions, such as solution "10 - Mechanics PTO independent", concerning only a small and rare part of the process, the probability that it will contribute to efficiency in the process is much smaller.

Conclusion

Table 14 in Chapter 4 has drawn up the requirements of all main actors, so that the solutions in Table 16 could be evaluated in Chapter 6. When looking at Table 16, it shows how the solutions meet the requirements. It can be concluded that all solutions, except the ones dealing with actual failure, are beneficial for the customer experience. As explained, the negative customer experience will be compensated by the fact that the demand-driven maintenance will be combined by taking urgency into account. When all categories of demand-driven maintenance are combined, this ultimately has a positive influence on the customer experience.

In addition, the solutions have a positive influence on almost all other requirements of the main actors, so that it can be concluded that the solutions contribute to less waste and more efficiency in the maintenance process. This is ultimately, in addition to ensuring a pleasant journey for the traveller, the goal of all main actors.

Then Table 17 looked at the prioritisation criteria for the implementation of the solutions. Because, as was shown in Table 15 in Chapter 5, all solutions address all the inefficiencies of Chapter 3, but cannot be implemented all at once.

In general, it can be concluded, that when looking for solutions to prevent inefficiencies/waste in a maintenance process in a principal-agent cooperation, it is important that, besides improving the economic relevance to achieve a better economic optimum, also solutions should be considered to ensure reduction of trust issues. This leads to better cooperation between the cooperating parties and eventually to a better customer experience.

The four solution directions which should be implemented first for this case study are (see Table 16 and Table 17): an alternative maintenance strategy (solution 1 and 2), more transparency in Service Now about failure data and user data (solution 5), the application of Demand-driven failure prioritization (solution 6 and 7) and lastly the prevention of unnecessary and repeated processes (solution 13 and 14), are important for this case study to improve both the economic relevance and the customer experience.

However, these solution directions can also be generalized, because with other maintenance fields these will also be essential aspects that can cause potential inefficiencies: The right maintenance strategy, transparency, no unnecessary procedures and processes and demand-driven failure prioritization (see Figure 23).

7. Conclusions and recommendations

Having looked at the current Thales maintenance procedure on the NS station resources on the basis of a qualitative investigation through interviews and observations and a quantitative investigation on the basis of data analysis of all incidents in the past three years, conclusions and recommendations can be drawn regarding the maintenance efficiency and further research.

In Chapter 7.1 the main research question will be answered as a final conclusion of this study, followed by some possible limitations regarding this study. Finally, a set of recommendations will be defined in Chapter 7.2.

7.1. Conclusions

Research has been done on economic relevance and different types of maintenance strategies for electronic registration systems for public transport companies. Limited research has been found on this topic. All relevant research did not take inefficiencies caused by a principal-agent relationship into account. This research uses the NS and Thales collaboration to build an in depth analysis on how maintenance can be better organised and result into an approved business outcome.

The outcome of this research provides a scientific contribution for comparable systems such as electronic registration systems for other train, bus, tram and subway operators in the Netherlands since they all work with the OV card. Also ATM systems used by banks have a similar maintenance situation and can therefore benefit from this research. This research outcome can be used to increase the efficiency of maintenance for similar systems.

In this subchapter, the main research question will be answered in Chapter 7.1.1 and the limitations of this research will be discussed in Chapter 7.1.2.

7.1.1. Answering the main research question

With the objective of this research as a starting point, the main research was defined as:

How can the maintenance process of the station resources of the NS and Thales be improved without negatively impacting travellers' experience?

To find an answer to this question, primary five research sub-questions were answered. Answering the sub-questions, it became clear how the current maintenance process of the station resources works, what the requirements of the process are and what inefficiencies are currently occurring.

It can be concluded from this case study that - when making maintenance processes more efficient - the social side of cooperation is an important aspect to take into account alongside economic relevance. In addition to inefficiencies that arise from the maintenance process, duplicate and unnecessary processes, inattention from staff and no transparency in data, also inefficiencies due to trust issues from the principal-agent cooperation do exist. In this case, the NS does not trust Thales' to do the maximum possible to limit the nuisance for travellers. Also the NS would like to see Thales taking more accountability on the traveller experience instead of only acting on the SLAs in the contract. Meanwhile Thales believes that the costs have become too high because of the SLAs that they have to meet according the contract. Besides that, they are assessed on the current SLAs, so that is the explanation why they do not change their behaviour to meet the travellers experience in a better way. All these issues stand in the way of efficiency in the maintenance process and a higher traveller experience.

To increase economic relevance, it is important that the process is efficient and the waste is minimal. In this case, the customer experience will increase, when the principal-agent collaboration is improved. From this, it can be concluded that four improvement directions are the most important. In no particular order, these are; 1) a different maintenance strategy, 2) the prevention of unnecessary procedures and processes, 3) transparency in data and 4) demand-driven failure prioritisation.

Literature but also the experience from the case study shows that the NS and Thales should focus on preventive - or on the longer term - predictive maintenance. Periodic maintenance causes less inconvenience compared to reactive maintenance, due to the fact that the work can be planned and the dissolution time is shorter. That is why the process will be more efficient and closer to the optimum of economic relevance.

The prevention of unnecessary procedures and processes ensures that the process of every failure is more efficient. By creating more transparency in data on disruptions and the prevention of duplicate and unnecessary processes, people from both the NS and Thales gain time for better analyses. Last, resolving disruptions on the basis of a different prioritization should work if the urgency or impact is considered.

Due to the four solutions mentioned above, the requirements of all the main actors are improved. Especially customer experiences will be better. So the main goal is better achieved, without increased travel times and without increasing the cost base. In addition, all solutions presented in this research will result in less disruptions and better maintenance service, which will strengthen confidence and therefore the trust of the NS in the service of Thales. At last, one full-service contract for all station resources that includes a greater diversity of SLAs will also contribute to a more desirable behaviour by Thales.

The main research question could be answered: The maintenance process can be improved by opting for a different maintenance strategy, by not allowing unnecessary and repeated processes to happen and by looking better at the needs of the traveller.

Two generic lessons, also illustrated in Figure 23, from this case study:

- When looking for solutions to prevent inefficiencies/waste in a maintenance process in a principal-agent cooperation, in addition to improving the economic relevance, also solutions are covered to ensure reduction of trust issues.
- The following aspects are important to prevent inefficiencies in maintenance processes:
    - The maintenance strategy
    - Transparency in data
    - Demand-driven maintenance
    - No unnecessary and repeated processes

  All these aspects have a specific solution proposed in this study, but are also valid for other processes in other maintenance fields.

7.1.2. Limitations of the research

Just like any other research, this research has some limitations. The most important limitation is that the study was conducted in a real working environment. As every organisation works differently, inefficiencies identified in the study, cannot necessarily be translated to other maintenance companies. Therefore, it is challenging to distil general practices from this work. Nevertheless, a few general conclusions can be drawn. However, it remains to be seen how applicable these are outside the scope of this study.

A secondary disadvantage is that the solutions for the identified inefficiencies could only be tested qualitatively and not quantitatively in this research period. Time constraints prevented the implementation of the solutions in the evaluated maintenance process.

As a result, it was not possible to conduct a full validation and it is difficult to assess which of the proposed solutions would form the biggest contribution to reducing inefficiencies and improving the traveller experience in relation to disruptions to station resources

7.2. Recommendations

In this final chapter, a set of recommendations will be defined. First, some recommendations are made for further research in Chapter 7.2.1. Second, some practical recommendations for the NS and Thales are given in Chapter 7.2.2.

7.2.1. Recommendations for further research

Firstly, during the research period, an assumption was made about the inconvenience experienced by travellers related to disruptions to the station resources. It was assumed that all malfunctions would cause nuisance, but is not necessarily true. When enough alternatives are at hand within a certain convenient zone and no disputes or unsafe situations arise, there will be little to no nuisance experience by the unavailability of the indisposed resources. It is therefore important that the nuisance is quantified, so the impact of solutions can be better evaluated.

It should be noted that, although the nuisance in the current research was an assumption and could not be measured, the solutions are still relevant. The identified inefficiencies of both the NS and Thales in the current process will, if resolved, ultimately lead to greater efficiency and therefore lower costs and increased profits.

The second recommendation for further research concerns the long-term effect on the equipment. During this research, it was assumed that the equipment would remain the same. However, with the rapid technological developments, there is a possibility that in a few years a vastly different set of equipment will be used. The requirements of the system can change as a result these development and in parallel the demands of how the maintenance system should be set up, may alter. Hence, future research can look at the wishes and requirements of ticket validation and sales equipment in the context of maintenance provision. This could prevent that future maintenance contracts are too static.

7.2.2. Recommendations for the NS and Thales

Examining the implementation of the proposed solutions in this research, the recommendation is to start with the cooperation between the principal and the agent. This research has shown that the social aspect is also very important, in addition to the prevention of process inefficiencies.

A way to improve the social aspect trust in the service of Thales is by demand-driven failure prioritization and more transparency in data. This is complemented by implementations recommendations.

The demand-driven failure prioritization based on the urgency factors and the actual fault, as indicated in Figure 21, needs to be specified. Figure 22 gives an example of a possible arrangement of the categories that determine the priority and secondly the SLA. A 1-hour SLA here applies for a failure with the priority 1 and a 72-hour SLA for a failure with a low (5) priority. As explained in Chapter 5.2 with the proposal in Figure 22, not all factors have been taken into account. It is therefore desirable to conduct further research into how this component, demand-driven maintenance, can be best set up for the NS and Thales.

Lastly, it is also important to note the availability of data. This research concludes that there is a need for more data transparency, see section 5.3. This includes data from the failures, but also data on the usage of the equipment. Excess data may not necessarily be beneficial, but useful data should be more widely shared. It is, therefore, recommended to share information needed to prevent repeat failures, to conduct research for preventive and predictive maintenance, and to determine which data is helpful in improving the current maintenance strategy .

Appendix

1. Scientific article

To fulfil the requirements of this graduation project, a scientific article is written. This article can be found from the next page on.

Exploring improved maintenance strategies of railway registration systems at the intersection of principal-agent theory and economic relevance: A case study

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Master Transport, Infrastructure and Logistics, TU Delft – May 2019

Abstract

Since 2011, an electronic registration system, called the OV chip card, has been in use in the Netherlands for the payment of all public transport. As a result, the Dutch Railways (NS) have implemented all the necessary equipment to support the sales and validation processes of this system. Another company (Thales, the agent) has been hired to maintain all these resources on behalf of NS (the principal). In this paper, qualitative and quantitative research into the current maintenance process has been carried out. This research shows that various inefficiencies occur in the current maintenance process. The most important ones are unnecessary process steps for the mechanic at Thales, multiple Work Order Tasks to solve single incidents and the difficulty to plan efficiently due to the many fatal failures. Additionally, this study shows that collaboration between the principal and the agent is an essential factor which can undermine efficiency. An important example of inefficiency due to poor collaboration is the occurrence of repeated failures. This is caused by a lack of transparency on past maintenance of particular resources. In this case study, four crucial improvement directions are identified. In no particular order, these are a different maintenance strategy, the prevention of unnecessary and repeated processes, transparency in data and demand-driven failure prioritisation. Generalisation of this research is difficult, but this study shows that in complex maintenance situations problems can be solved with both technical and procedural adjustments, as well as by improved cooperation between the party that commissioned the maintenance and the party who then performs the maintenance.

Keywords: Electronic Registration Systems – Public Transport - Process optimization - Maintenance Strategies – Economic Relevance – Principal-Agent cooperation

1. Introduction

Implementation of novel technologies leads to many alterations in the manner businesses are run. This has been vividly apparent in the implementation of electronic card systems across different industries. Card payment systems have enabled people to pay by card (Wróbel-Konior, 2019), to use their mobile phones to check in at the airport and has eliminated the need for physical tickets to access amusement parks. With the introduction of these card systems, the need for electronic registration systems grew in parallel. One example of an electronic card system is the OV chip card in the Netherlands (van der Zwan, 2011).

This system offers many advantages, but its use is limited by certain disadvantages (Leijten, 2014). From a traveller's point of view, delays need to be avoided. As trains run at strict time schedules, additional actions by the passenger – needed for the validation and sales of the OV chipcard and time-consuming due to limited station resourced- may severely impact the customer experience. The current average availability of the station resources is at least 99% (NS, 2018). This percentage is already very high. On average 300 (BSM, 2018) disturbances of station resources are registered per week. Even this relatively small amount of disturbances can influence the traveller's comfort in a negative way.

Any disturbance should be placed in a context in order to validate the impact for the traveller. In some cases the impact can be huge and in other cases a disturbance may not influence travellers comfort at all. Therefore the reported 99% availability can give a distorted picture. For this reason this research looks into the failures that occur at the station resources of the Dutch Railways (NS) and the inefficiencies in the maintenance process.

In the past, maintenance problems received little attention and research in this area was of low impact. Today, this is changing as the increased importance of effective maintenance in the new industrial environment is acknowledged. Maintenance, if optimised, can be used as a key factor in organisation's efficiency and effectiveness. It enhances both the organisation's ability to provide competitive services and aides the company to meet its stated objectives (Ben-Daya, Duffuaa, & Raouf, 2000).

This research aims to present both a practical and scientific contribution. The NS-Thales case provides a good opportunity to gain new empirical knowledge on maintenance strategies for these types of registration systems. Secondly, it provides a scientific contribution because the research is grounded in technical and economic improvements theories, as well as cooperation-, assignment- and contracting issues arising from the principal-agent theory (Braun & Guston, 2003).

This article is structured as follows. The next section shows the methodology which is applied for this research. The third section provides the theoretical background in the field of the principal-agent theory, different maintenance strategies and the theory behind the economic approach of maintenance. The fourth section introduces the case study environment and the fifth section will describe the designed solutions and their discussion. Subsequently, the conclusions of this study are drawn in Section 6 and recommendations for future research are given in Section 7.

2. Methodology

For this research, a methodological framework (Figure A) has been used based on the *metamodel of design* (Herder & Stikkelman, 2004).

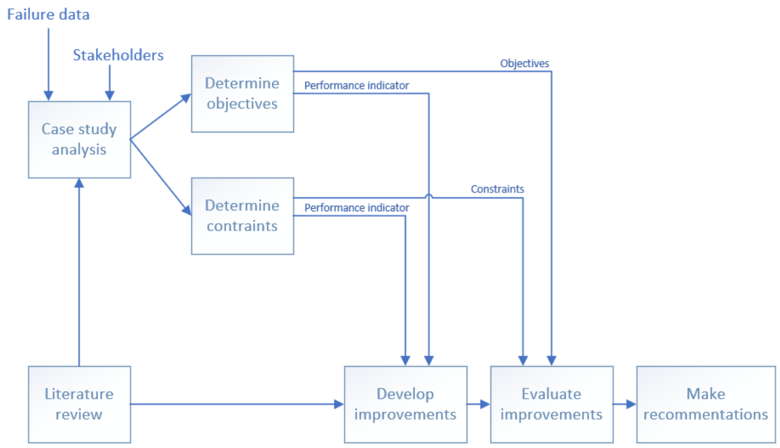

Figure A, Methodological framework, based on the metamodel of design (Herder & Stikkelman, 2004)

A literature review is carried out on different theoretical topics because this provides a starting point in terms of knowledge and insights for the further research. Subsequently a case study analysis is done based on qualitative and quantitative research to determine the objectives and constraints for the improvements of the maintenance service of Thales.

Qualitative research was done through interviews, document analysis, such as the contracts, and observations within the system. Interviews were held with travellers, experts, people from the management team, as well as executive personnel at both the NS and Thales. In addition, a working day in the life of a Thales mechanic is observed, and the incident process at the planner and qualifier at Thales and the NS Operation Centre is observed. Secondly, quantitative research was conducted for the case study and a data analysis on all failures was used to gain a better understanding of the meaning of a failure.

Through these analyses, the current process and its inefficiencies of maintaining the station resources could be ascertained. Applying the knowledge from the literature, evaluating the detected inefficiencies and employing the experience gained during the analysis of the interviews and field observations, proposals were made for designs to improve the current situation and move towards the preferred situation.

These improvements are evaluated and the implementation prioritized. Finally, conclusions are drawn and recommendations made for additional research to further improve the maintenance process of the station resources in the future.

3. Theoretical background

In this research, it is assumed that efficient (or improved) maintenance strategies will not only depend on economic maintenance theory, but also on principal-agent theory. In the case of cooperation between different parties there may be a common main objective, but each party always has its own interests to which it acts. It is therefore deemed important that the principal-agent theory is also included in the research, because it considers how issues such as trust and power imbalances can be resolved and does not limit its scope to economic relevance, maintenance strategies and quantitative data research to improve maintenance.

In this section, the theoretical background will be provided to the research fields of the principal-agent theory, the theory behind the economic approach of maintenance and theory on different maintenance strategies. These research fields will help to provide a starting point in terms of knowledge and insights to the field of maintenance of the station resources.

3.1. Principal-Agent theory

The principal-agent literature deals with a specific social relationship, that is, delegation, in which two actors are involved in an exchange of resources. The principal is the actor who possesses a number of resources, but he requires an agent when he is not those of the appropriate kind to realise the interests (Braun & Guston, 2003). Between these two parties, there is usually a hierarchical structure.

There are two typical collective action problems of the principal-agent structure discussed in the literature; moral hazard and adverse selection. These problems are based on what the new institutional economics (Moe, 1984) calls the 'opportunism' of actors. Actors are self-interested and thus seek to maximise their own welfare. The principal does not know whether the agent will really do its best when it is delegated certain tasks. This is the "moral hazard", and usually the principal does not have sufficient information on the abilities of potential agents to find the one best suited to do the task. This is "adverse selection" (Braun & Guston, 2003).

The two aforementioned collective action problems are primarily caused by three things; First of all, full cooperation is often limited by the heavy *power imbalances* between partners. By maximising their own profits, powerful companies mostly prevent other parties from getting benefits or may even force them into a loss (Hingley, Lindgreen, & Casswell, 2006). The second and most important cause as mentioned by multiple studies is *trust*. Companies are afraid that their willingness to cooperate will be misused by their partner. This is also mentioned by Zhao et al.: "Many companies are reluctant to share information with their trading partners, afraid that the information will be used unfairly to their disadvantage" (Xiande Zhao, 2002). It is difficult to judge if partners only optimize their own processes instead of working towards an optimum performance (Parkhe, 1993). This is reinforced by the fact that the chain optimum is not equal to the summed optimal of each partner (Northcraft, 2007). Lastly, *the willingness of partners to change behaviour* in favour of the other party can be an issue. Therefore, even when all information is disclosed, there is no guarantee that the information is used by partners to increase revenues besides their own (Pereira, 2009).

It can be concluded that the relationship between the NS and Thales in the maintenance of the station resources can be described as a principal-agent relationship. Hence, this aspect must be taken into account during the interviews, observations and in the quantitative data analysis. Power imbalances, trust issues and the unwillingness to change behaviour can lead to inefficiencies in the corporation and thus the maintenance process of the station resources of the NS.

3.2. The economic relevance of maintenance

When looking at maintenance and the way it is carried out, costs play an important role. When servicing station resources, it is essential that the costs are lower than the income to ensure a company makes profit (Leonard, 2018) (Watkins, 2019). This results into a positive cost-benefit ratio.

To make maintenance economically relevant, an optimum must be found for two aspects 1) investments versus costs and 2) maintenance versus costs (Woodward, 1997). The best cost-benefit ratio will be referred to as the economic relevance optimum.

When considering investments in new equipment versus the maintenance of existing equipment, there are two extreme scenarios. In the first extreme, it can be an advantage to use existing equipment for as long as possible. The investment costs in new equipment are low, but the result of this strategy is that parts are increasingly out-of-use and a lot of maintenance is needed to repair the equipment. The maintenance costs are therefore high and disturbances cause inconvenience to users, which can also be expressed in costs. In the opposite extreme, investments in new equipment are made every year. This can be advantageous because the equipment will rarely break down and the maintenance costs will be low, but the investment costs could be enormous. There is an optimum between the two extremes, where the cost benefit ratio is positive.

Secondly, there is an inverse relationship between the costs and the maintenance strategy. A reactive approach reduces maintenance expenditures but increases loss of use due to downtime. A periodic maintenance policy, on the other hand, reduces the downtime costs. It is essential that a periodic maintenance policy is maintained for those items of equipment that incur high downtime costs whereas items of equipment incurring low downtime costs can be attended to or replaced as they wear out. The key factor is to find an optimal level of maintenance service in order to be consistent with the organisation's objective of attaining minimum total cost (Woodward, 1997).

Therefore, it can be concluded that the economic aspect of maintenance must be taken into account during the interviews, observations and in the quantitative data analysis, as the NS and Thales are both commercial companies that have to earn money.

3.3. Maintenance strategies

Effective maintenance is increasingly critical to many operations. It extends equipment life, improves equipment availability and retains equipment in proper condition. Conversely, poorly maintained equipment may lead to more frequent equipment failures, poor utilisation of equipment and delayed production schedules. Misaligned or malfunctioning equipment may result in scrap or products of questionable quality. Finally, poor maintenance may mean more frequent equipment replacement because of shorter life spans (Swanson, 2001).

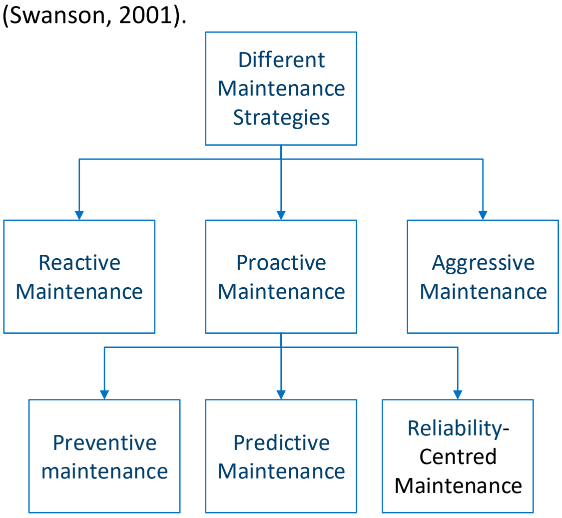

Figure B, Overview maintenance strategies

Many authors have described different strategies for maintenance management, see Figure B. In general, maintenance techniques can be divided into three branches. In the first branch, maintenance only takes place if the system has stopped working and is called reactive maintenance. In the second branch, proactive maintenance tries to foresee upcoming problems in the system to prevent total failure. Preventive, predictive and Reliability-Centred Maintenance represents three proactive strategies by which companies can avoid equipment breakdowns (Bateman, 1995). The third branch includes aggressive maintenance techniques, like Total Productive Maintenance (TPM) (Weil, 1998), which have emerged, since advances in personnel qualification and information systems have made them viable. They propose an all-encompassing strategy to achieve better performance while lowering failure rates (Swanson, 2001).

All these strategies have different advantages and disadvantages (Swanson, 2001) (Baglee, Maintenance Strategies, 2018) (Hansford Sensors, 2018). Especially the current reactive maintenance strategy has a lot of disadvantages; unpredictability and fluctuation of production capacity, higher levels of out-of-tolerance and scrap output, and increased overall maintenance costs to repair catastrophic failures (Bateman, 1995) (Gallimore & Penlesky, 1988).

From this, it can be concluded that instead of the currently applied, mainly reactive maintenance strategy, it is important that another strategy is applied to prevent disruptions. From the strategies in this section, it appears that aggressive (TPM) maintenance is not possible because the maintenance scope of Thales does not extend that far in the process (Nakajima, 1989) (Ahuja & Khamba, 2008) (Mishra, Anand, & Kodali, 2007). According to the contract, Thales is only active in the operation and failure zone and in consultation they also do installation & commissioning and replacement of equipment (Kelly, 2006). Proactive maintenance, on the other hand, is possible.

The preventative proactive maintenance is the cheapest to implement. However, with this strategy it is difficult to estimate when maintenance is truly necessary, because it is only based on use. As a result of this, unneeded maintenance is carried out, which also incurs unnecessary costs (Gits, 1992) (Herbaty, 1990). This is not the case with predictive maintenance and RCM, as the maintenance is determined by estimating and repeatedly checking the life time of equipment components (Vanzile & Otis, 1992) (Gits, 1992). These strategies are therefore better aligned with achieving the economic optimisation discussed in section 3.2. Both predictive maintenance and RCM can be applied to the maintenance of the station resources of the NS. However, RCM entails higher start-up costs than predictive maintenance strategy (Dekker, 1996) (Sharma, Kumar, & Kumar, 2005). This additional expenditure does not outweigh the possible benefits of the RCM maintenance strategy, making predictive maintenance the best maintenance strategy for the station resources. This strategy has therefore the best benefit-cost ratio.

However, this can only be implemented in the long-term, because lots of research needs to be done before this strategy can be implemented. In the short term, preventive maintenance should take place, as this implementation requires less research. Alongside preventive maintenance, reactive maintenance continues to exist, because, as Gassner (2009) stated, there will always be occasions where the system unexpectedly breaks down and reactive maintenance is needed. No matter how well mechanics are maintained, something can always break electronically. However, the ratio in which the maintenance strategies are currently being implemented have to change, so that an increasing number of failures is averted by preventative maintenance and less reactive maintenance is required.

4. Case study

A case study research allows the exploration and understanding of complex issues. It can be considered a robust research method particularly when a holistic, in-depth investigation is required (Zainal , 2007). An advantage of a case study is the possibility to obtain an overall picture of the research object (Verschuren & Doorewaard, 1998).

In this case study, the NS has implemented all the necessary equipment to support the sales and validation processes of the OV chipcard. As mentioned in Section 3.1, the relationship between the NS and Thales in the maintenance of the station resources can be described as a principal-agent relationship. The station resources are owned by the NS (principal), but the NS hires Thales (agent) to carry out the maintenance. They have a common interest, namely that *travellers can use the station resources in the best way possible*, so the main goal is to create the highest customer experience as possible. However, both parties also have their own interests which do not always align. The business model of Thales is based on profit, while the NS also has a social function. If a station resource is a nuisance, the traveller will blame the NS and not Thales.

The maintenance provisions are captured in two contracts; the OVCP full-service contract for the gates and the CiCos and the TODI contract for the ticket vending machines, ticket counter systems and the information and alarm columns, where Thales is paid for each repair carried out by a mechanic. As explained in section 3.3, both contracts are constructed primarily on a reactive maintenance strategy.
The maintenance is carried out on the basis of Service Level Agreements (SLAs), which are defined in the two contracts. When a failure occurs, standard forms are used to judge whether a failure is fatal (immediately resulting in significant discomfort for the traveller) or non-fatal (not obstructing the traveller to travel successfully). The SLA determines that if a failure is fatal, it must be resolved within 4 hours by Thales and if it is non-fatal within 72 hours (NS Groep N.V. & Thales Transportation Systems B.V., 2018). Other aspects are not included in this provision.

In 2018 the average number of failures was 1047 per month, of which 85% were fatal failures. The ticket machines and service desks give the most incidents. The cause of a failure varies greatly, it can be caused by vandalism or user errors, but the most frequently a failure is the result of hardware or software failures.

Based on the qualitative and quantitative analyses of the current maintenance process, inefficiencies, also known as waste, and scarce resources such as time, money, physical materials and personnel, are determined (Banton, 2019) (Visser, Matten, Pohl, & Tolhurst, 2007). It appears that a flawed maintenance strategy, unnecessary repetitions and negligence by employees at both NS and Thales cause inefficiencies in the process. This is complemented by issues which arise from the principal-agent cooperation between the NS and Thales, in particular trust issues.

Due to the inefficiencies that occur, the requirements from the NS, Thales and the traveller are not met, i.e. a low number of (repeat) failures, high equipment availability, a low dissolution time, low equipment, transportation and staff costs and high customer experience. Consequently, this research has looked at solutions to prevent these inefficiencies in the future.

5. Design of improvements

In this section the most important solutions are described which should be implemented first to make the maintenance process as efficient as possible.

Different solutions have been developed to address the inefficiencies in the maintenance process of the station resources of the NS. However, not all solutions can be implemented at once. Hence, the implementation is prioritized based on various criteria and in consultation with experts from the NS and Thales.

From the literature and experience gained during this research, it seemed that for all companies economic relevance was most important. This can be achieved by increasing the process efficiency. Furthermore, this case study has shown that collaboration is an essential factor, which can improve the customer experience. A key driver for both NS and Thales are solutions, which will better fulfil the requirements of all actors. Solutions therefore need to have a large reach/impact. The improvement of inefficiencies which occur at every failure, has a significantly larger effect than the resolution of sporadic inefficiency. If a solutions desired effect is uncertain, it should not be given priority for implementation.

Based on this knowledge, four criteria were chosen to determine what priority should be assigned to implementing particular improvements: 1) improvements in economic relevance, so that the economic optimum is better achieved, 2) improving trust so that the principal-agent cooperation gets better and eventually the customer experience, 3) the reach of the solution, or alternatively, does the solution have any effect on all failures or only occasionally. And lastly, 4) the probability that the solutions will achieve the desired effect.

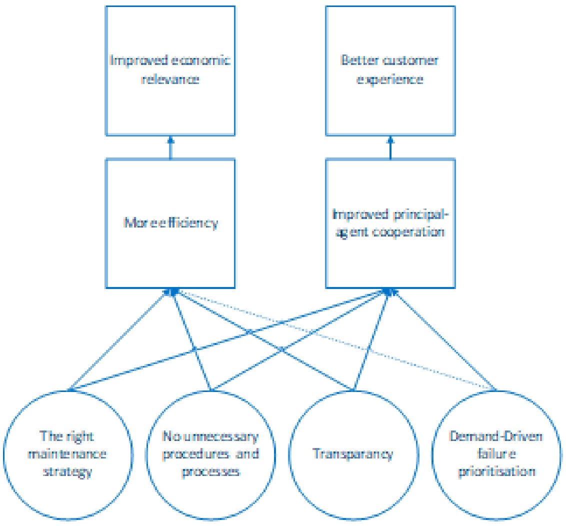

Figure C, Concluded relation between scientific concepts

From this, it is concluded that four, improvement directions are most important. In no particular order, these are a different maintenance strategy, the prevention of unnecessary and repeated processes, transparency in data and an alteration of the failure prioritisation.

Figure C shows how these aspects are interrelated in this case study and could be applied to other maintenance improvements in comparable fields.

5.1 The right maintenance strategy

The literature shows, see Section 3.3, that a different maintenance strategy should be applied to the maintenance of the station resources of the NS. If there is the possibility of preventing failures by introducing maintenance on time, this saves time and, therefore, also reduces traveller inconvenience (Lenahan, 2006). Reactive maintenance, which is currently primarily applied, has many disadvantages (Hansford Sensors, 2018), including unpredictability, high costs and an inefficient use of staff. It is therefore proposed to implement a preventive maintenance strategy and, in the long term, move toward a predictive maintenance strategy. One of the advantages of periodic maintenance is less inconvenience to the traveller compared to reactive maintenance, as it can take place at favourable times and the dissolution time is shorter. In addition, predictive maintenance allows the lifetime of equipment to be more accurately determined, resulting in the optimization of economic relevance. The explanation for this occurrence is that maintenance is performed at the correct time and the equipment is only replaced when it has been demonstrated that it will fail soon. As a result, the NS and Thales do not have to carry out excessive maintenance. This will lower the (equipment) costs, compared to preventative maintenance, where equipment may be replaced prematurely. This means currently no economic optimum can be achieved according to the economic theory.

5.2 No unnecessary procedures and processes

An alternative maintenance strategy has advantages, but as literature and experiences from this maintenance field indicate, reactive maintenance will always be needed, because it is impossible to prevent all incidents. Thus, this research also investigates the current process to prevent inefficiencies for the future. Therefore, it is examined whether repeated and unnecessary processes could be avoided. On the one hand, more efficiency requires adjustments to the current process. For example, unnecessary telephone contact between the mechanic and the NS must be avoided and the physical booklet that keeps track of the work done on a piece of equipment must be removed. This creates one central location with all the information on failures, instead of the information asymmetry that occurs when information is distributed across multiple locations and platforms.

5.3 Transparency

Additionally, adjustments to the existing systems have to be made to prevent processes being duplicated, but most importantly, there must be more transparency in data. Data about all the failures at the station resources due to both the Thales and the NS reboots, but also user data. When more transparency is provided in the failure data and with the prevention of duplicate and unnecessary processes, people from both the NS and Thales have more time to do more thorough analyses of failures that occur. As a result, lessons will be learnt from the (repeated) failures that have taken place, and a preventative strategy can be put in place. This ultimately means that the traveller experiences less nuisance and has a better customer experience.

Increased transparency may also alleviate part of the trust problem at the NS, because the traveller experience is improved.

5.4 Demand-driven failure prioritisation

The service of Thales becomes even better if they act more in line with the current needs of the traveller. This can best be achieved by considering the urgency of the fault, as well as the actual fault when prioritising repairs. As a result, disruptions with a high urgency are resolved faster than a disruption at, for example, one gate within a row of 20 alternatives. Here all the requirements of the traveller are met, such as no waiting time and a safe situation. Applying this approach, Thales takes the needs of the traveller better into account, making the NS more trustful about the service that Thales provides.

6. Conclusions

This section presents the conclusions and limitations that have emerged from the research that has been conducted. In section 6.1 conclusions of this research are drawn and in section 6.2, the limitations of the study are mentioned.

6.1 Conclusions of the research

It can be concluded from this research, when optimisation of maintenance processes is considered, it is necessary to examine solutions which can improve both the economic relevance and the principal-agent cooperation. Typically efficiencies are only judged on economic relevance. Also a hampering collaboration between parties can still cause inefficiencies. It can be concluded from this research that both aspects must be taken into account in order to achieve the desired maintenance situation.

To increase economic relevance, it is important that the process is efficient, and the waste is minimal. In this case study, the secondary goal, the customer experience, will be enhanced, when the principal-agent collaboration is improved. Thus, it can be concluded that four improvement directions are most important. In no particular order, these are; 1) a different maintenance strategy, 2) the prevention of unnecessary procedures and processes, 3) transparency in data and 4) demand-driven failure prioritisation.

These four solutions will solve many of the inefficiencies in the maintenance process of the station resources and the inconveniences experienced by the travellers. Furthermore, these improvements can be applied to prevent inefficiencies in other fields of maintenance. The actual implementation may differ, but it is most advantageous for the user if right maintenance strategies to resolve disruptions are applied in a demand-driven manner.

6.2 Limitations of the research

Just like any other research, this research has some limitations. The most important limitation is that the study was conducted in a real working environment. As every organisation works differently, inefficiencies identified in the study, cannot necessarily be translated to other maintenance companies. Therefore, it is challenging to distil general practices from this work. Nevertheless, a few general conclusions can be drawn. However, it remains to be seen how applicable these are outside the scope of this study.

A secondary disadvantage is that the solutions for the identified inefficiencies could only be tested qualitatively and not quantitatively in this research period. Time constraints prevented the implementation of the solutions in the evaluated maintenance process.

As a result, it was not possible to conduct a full validation and it is difficult to assess which of the proposed solutions would form the biggest contribution to reducing inefficiencies and improving the traveller experience in relation to disruptions to station resources

7. Recommendations

In this final section, a set of recommendations is defined. Firstly, some recommendations are made for further research in Section 7.1. Secondly, some practical recommendations for the NS and Thales are given in Section 7.2.

7.1. Recommendations for further research

Firstly, during the research period, an assumption was made about the inconvenience experienced by travellers related to disruptions to the station resources. It was assumed that all malfunctions would cause nuisance, but is not necessarily true. When enough alternatives are at hand within a certain convenient zone and no disputes or unsafe situations arise, there will be little to no nuisance experience by the unavailability of the indisposed resources. It is therefore important that the nuisance is quantified, so the impact of solutions can be better evaluated.

It should be noted that, although the nuisance in the current research was an assumption and could not be measured, the solutions are still relevant. The identified inefficiencies of both the NS and Thales in the current process will, if resolved, ultimately lead to greater efficiency and therefore lower costs and increased profits.

The second recommendation for further research concerns the long-term effect on the equipment. During this research, it was assumed that the equipment would remain the same. However, with the rapid technological developments, there is a possibility that in a few years a vastly different set of equipment will be used. The requirements of the system can change as a result these development and in parallel the demands of how the maintenance system should be set up, may alter. Hence, future research can look at the wishes and requirements of ticket validation and sales equipment in the context of maintenance provision. This could prevent that future maintenance contracts are too static.

7.2. Recommendations for the NS and Thales

Examining the implementation of the proposed solutions in this research, the recommendation is to start with the cooperation between the principal and the agent. This research has shown that the social aspect is also very important, in addition to the prevention of process inefficiencies.

A way to improve the social aspect trust in the service of Thales is by demand-driven failure prioritization and more transparency in data. This is complemented by implementations recommendations.

The demand-driven failure prioritization must be specified. It is stated in section 5.4 that the urgency of a failure must be taken into account; besides noting the actual failure, a priority needs to be assigned. However, it is desirable to conduct further research into how this should be implemented for the NS and Thales.

Lastly, it is also important to note the availability of data. This research concludes that there is a need for more data transparency, see section 5.3. This includes data from the failures, but also data on the usage of the equipment. Excess data may not necessarily be beneficial, but useful data should be more widely shared. It is, therefore, recommended to share information needed to prevent repeat failures, to conduct research for preventive and predictive maintenance, and to determine which data is helpful in improving the current maintenance strategy .

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2. Pros and cons of the different maintenance strategies

(Swanson, 2001) (Baglee, Maintenance Strategies, 2018) (Hansford Sensors, 2018)

Strategy	Pros	Cons
Reactive Maintenance	-Minimal planning is required -The process is very simple -Less staff required as less work is done day-to-day -Ideal for low priority equipment	-Failure is highly unpredictable -High costs due to unplanned downtime of equipment -Increased labour costs, especially if overtime is needed -Costs involved with repair or replacement of equipment -Possible secondary equipment or process damage from equipment failure -Inefficient use of staff resources
Preventive Maintenance	-Cost effective in many capital intensive or potentially high impacts processes -Flexibility allows for the adjustment of maintenance periodicity -Increased component life-cycle -Reduced equipment or process failures	-Catastrophic failures still likely to occur -Labour intensive -Performance of unneeded maintenance -Incidental damage to components through poor maintenance practices
Predictive Maintenance	-Increased component operational life/availability -Allows for pre-emptive corrective actions -Reduced equipment or process downtime -Decreased costs for parts and labour -Better product quality -Improved worker and environmental safety -Improved worker morale	-Increased investment in diagnostic equipment -Increased investment in training of staff -Savings potentials not readily seen by management
Reliability Centered Maintenance	-Can be the most efficient maintenance program. -Lower costs by eliminating unnecessary maintenance or overhauls. -Minimize the frequency of overhauls. -Reduced probability of sudden equipment failures. -Able to focus on maintenance activities on critical components. -Increased component reliability. -Incorporates root cause analysis.	-Can have significant start-up cost, training, equipment, etc. -Savings potential not readily seen by management.
Total Productive Maintenance	-Towards more efficiency in maintenance -Eliminating unnecessary maintenance or overhauls. -Minimize the frequency of overhauls. -Reduced chance of sudden equipment failure. -Focuses maintenance activities on critical components. -Increased component reliability. -Root causes of problems identified.	-Can have significant start-up cost, training, equipment, etc. -Savings potential not readily seen by management.

3. Analogue maintenance studies and cases

This part of the appendix examines analogue maintenance studies, to see how the maintenance in other fields is organized. Perhaps something can be learned or taken over to make the maintenance of the station's resources of the NS more efficient.

There will be looked at 4 different cases. First, connected cars, this is a field where predictive maintenance is already being applied. However, it is a very different sector than station resources. That is why there is also looked at the differences in maintenance strategy of other public transport companies in the Netherlands such as RET and GVB. In addition, the maintenance of ATMs on the street is also looked at in this Subchapter. These are resources in a completely different field, but with the same characteristics; They are spread throughout the country, but at fixed locations and when malfunctions occur, the user suffers from this. Finally, there is looked at the maintenance strategy of Ziggo. This case is discussed because Ziggo uses a different maintenance structure than Thales.

Connected cars

The automobile and fleet management industries, the majority of the consumers and the car service companies are following the 'periodic maintenance' for their automobiles. In periodic maintenance, car owners are advised to take their cars for regular service and maintenance either after a certain specified time period or distance covered. For example, it is generally advised to get the car serviced within three months of the last service date or after travelling 10000 kilometres, whichever comes first. Another instance where the car can be taken out for emergency service/maintenance is after some breakdown or malfunctioning of any part in the vehicle (Dhall & Solanki, 2017).

Some of the major drawbacks of periodic car maintenance are listed below:

- Higher cost of service, as vehicles are required to be get serviced as per the schedule
- Even if vehicle/parts are in perfect health, still service needs to done and parts to be replaced
- No way of knowing, if a part needs immediate attention, and can result in a breakdown of the vehicle
- This breakdown could cost significant charges for the car owners

Instead of getting a car serviced periodically, if a system developed using sensors and IoT technology stack is used, which collect and analyse fitness and running condition of different parts of the car, and send this data to a centralized system. In this centralized system, data received from these connected cars can be analysed further and if any service is needed, a service request can be raised. This proposed system can also generate emergency alerts, in case any part is about to break down, thus avoiding car/part failure. This type of maintenance is called predictive car maintenance (Dhall & Solanki, 2017).

The advantage of the proposed system:

- Reduction in service and maintenance costs, as only parts which needs to be replaced or serviced
- Real-time alerts of possible part failure, thus avoiding breakdown and costs associated with outages
- Analytics and reporting dashboards can be used to view how the car is performing over different periods of time and in different locations
- Driver's driving habits can be analysed and appropriate action can be taken
- Tour and cab providers can manage their fleet better, thus maximizing profits
- Target advertisements for monetization of data received from connected cars (e.g. offering service discounts for a car which needs to be serviced etc.)

However, there are also some challenges to this proposed maintenance system. For example, there is still a lack of industry standards and there is a need to have a proper IT analytics system in place, which can involve huge costs upfront. In addition, the purchase costs of the car will also rise very much because there are many more sensors still. Finally, better connectivity in terms of telecom, Bluetooth, Wi-Fi and other such networks for transmission or real-time data from sensors will be needed (Friedman, 2019) (Dhall & Solanki, 2017).

Most of the aforementioned advantages and disadvantages were also mentioned in Chapter 2.3.

RET, GVB, HTM, Qbuzz, Connexxion and Metro Amsterdam

The station resources of other transport companies such as RET, GVB, HTM are maintained by Thales in the same way as the station resources of the NS. The only difference is that the NS itself does the monitoring of the disruptions and then passes on the incidents to Thales instead of Thales also doing the monitoring as with the other transport companies.

This is the same principal agent structure because these parties also outsource a service to Thales that they themselves have no knowledge of.

ATMs on the street

ATMs on the street are resources that are very similar to station resources in terms of maintenance. All ATM vending machines are spread all over the country, sometimes have malfunctions and users experience a nuisance due to a malfunction. Because when an ATM fails, it can cost the operator a significant amount of time and money, not to mention the damage done to the operator's reputation.

At the moment the maintenance providers provide the same maintenance strategy as with the station resources; periodic and reactive. But also with this resource more and more sounds of people who think that there should be a change of maintenance strategy. They propose a proactive ATM maintenance strategy because it focuses on identifying and solving problems before they materialize. Because with reactive maintenance the organization isn't aware of a problem until it occurs, it might be forced to dispatch an engineer to the scene, which is costly and disruptive to the regular schedule. And, of course, the longer an ATM is down, the more business the provider loses. Consumers have grown increasingly impatient with slow and inconsistent self-service experiences, and become easily frustrated when the ATM they visit is down (Tomaney, 2016).

Given these facts, taking a proactive approach to ATM maintenance has some advantages over the reactive model. Two examples of preventive maintenance for ATMs have been proposed by Tomaney (2006); One type of preventative maintenance is typically performed by the engineer who has been sent to an ATM in response to the problem. While the engineer is at the ATM, they can carry out preventative maintenance in an attempt to prevent future issues by checking the top 10 known fault conditions while they're at an ATM. The second approach to proactive maintenance might be more attractive to organizations that wish to improve efficiency while lowering operational costs. This approach uses a monitoring agent onboard the ATM that automatically screens the behaviour of the device and records errors and warnings. When a fault is detected, the monitoring agent can execute local remedial rules to attempt a fix. If the problem cannot be resolved in this way, the system can forward the events to a central monitoring server for action (Tomaney, 2016).

Next, it is important that something happens with the collected data so that lessons can be learned for the future. For example, the monitoring server can analyse patterns from the data that might have led to the failure. By working backwards through the data to determine the sequence of events that occurred at the ATM before the failure, the system can potentially recognize the symptoms of a particular type of failure. If the system is aware that a pattern of X, Y and Z warnings might lead to error A, it can apply a rule set for a potential situation and alert the operator to the need for preventative action — for example, to replace a part that is expected to fail soon.

Using this approach means conducting maintenance on machines when they need it. The automated and adaptive nature of this approach also means that organizations can easily and quickly respond to changes in a machine. However, the problem most ATM providers encounter with this approach is that the only way to verify that an event or pattern indicates a particular outcome is to manually test the machine in the lab using data gathered from machines in the field. This is not only burdensome but also time-consuming, as it might take two to three months to thoroughly analyse the data. Only then can the operator accurately determine which errors can be avoided, how often a rule works, and how often the error still occurs despite intervention. From there, the tester can make a recommendation to test the rule again or to test other conditions instead.

However, in spite of these disadvantages, proactive ATM maintenance and monitoring can offer a clear competitive advantage to an organization that manages ATM networks and wishes to avoid the cost, expense and reputational damage associated with unplanned outages (Tomaney, 2016).

Ziggo

Ziggo delivers internet, telephone and television to people at home. This is a completely different service than the station resources of the NS, but it is comparable that there are devices in various places of Ziggo that require occasional maintenance. The maintenance strategy they carry out at Ziggo is regular maintenance and they also have predictive maintenance. Predictive maintenance is performed on the basis of KPIs within the machines. If for one component the values for the KPIs decrease, it is predicted that the component will soon break, that is why maintenance is scheduled at the moment of determining the decrease or increase in the values.

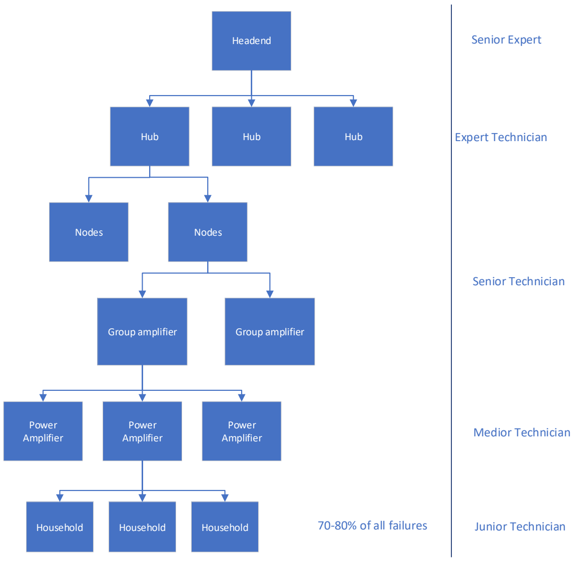


Figure I, Overview of the Ziggo resources

At Thales, almost every mechanic is PTO (public transport organisation) specific. This means that a mechanic can only repair all type of station resources of the NS or only of GVB. This is organized differently at Ziggo. Here you start as a technician and solve all faults in the households, Figure I. These are relatively the easiest faults and the most in number, 70-80%. If a technician has more experience, they will continue to become a medior technician that solves breakdowns at the end of the amplifiers and you will continue to grow in the organization to become a senior expert. The failures at this level are the most complex, but these people also have the most work experience (Knol, 2019).

Instead of PTO specific, technicians at Ziggo are therefore resourced specific. They start with the resource that gives the easiest failures and thus grow further and further in the organization, where they can solve increasingly complex resource failures with more experience.

Conclusion

The NS and Thales say that they want to change their maintenance strategy. This has, as stated in Chapter 2.3, advantages, but also disadvantages. The biggest advantage is that malfunctions can be prevented which reduce inconvenience for the user and maintenance costs because reactive maintenance cannot be scheduled and preventive but predictive maintenance can. But the downside is that switching to preventive and predictive maintenance costs a lot of time and money. In addition, the equipment is also becoming more and more expensive because the early detection of faults requires additional sensors in the equipment.

In other words, just as with NS and Thales, the switch to another maintenance strategy will not happen overnight. Step by step research will have to be done on failures as explained by Tomaney (2006) at the case of the ATMs on the street.

In addition to the maintenance strategy, it is also interesting to look at the maintenance organization. For example, Ziggo has a different approach, whereby the level of knowledge of the mechanics is gradually increased and mechanics start with "easy" equipment, preventing a lack of skills and knowledge so failures can be solved properly at once.

4. Stakeholder analysis

The purpose of the actor analysis is to identify the different actors that are involved in the environment where the maintenance of the station resources operates and to underpin which actors are important and less important for the research in this project. This is an important step in the research because every actor has wishes regarding the station resources, but some are more important than the others. So when mapping out what the most important actors are, it is clear what requirements must be considered for the process flow of the station resources. In Figure II the main actors involved are shown. Their power and interests are used to classify them in the different quadrants. Critical actors are those with a high level of power, *i.e.* important resources, while dedicated actors are those with a high level of interest in the problem (Enserink, et al., 2010).

The most important stakeholder in this research is the NS, department BSM (management station resources), as they are the owner and therefore responsible for all station resources. It has therefore the most power and interest in finding a solution to the research question. The rest of the main actors can be roughly divided into travellers, Thales Transportation Systems (TTS), the mechanics of TTS, Authorities, NS stations, Interest Organizations and third parties that Thales uses to carry out maintenance. In Figure II, they are categorised in the following categories: context setters, crowd, subjects and key players (Enserink, et al., 2010).

Because the NS owns all the resources it becomes the "key player". Besides them, two other key players are Thales and the travellers who use the station resources. The NS has more power compared to Thales because they can switch to another party that can carry out the maintenance. They also have more interest because the resources are part of travelling with the NS, so if they do not function properly, that will be bad for the services and finances of the NS. But since Thales in this study is the maintenance party that is responsible for all maintenance of the station resources, it is also a key player with a lot of power and interest. In addition, the travellers in this study are also key players, because whatever the outcome of the research question may be, the traveller cannot be deteriorated.

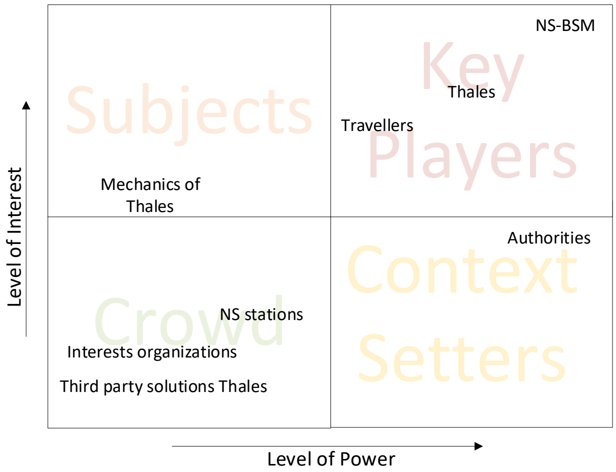


Figure II, Actor Analysis

The mechanics have very little power on the cooperation between NS and Thales, however, they are the "hands" of maintenance, so they do have a lot of interest in the possible efficiencies that arise from the research. Therefore they are regarded as "subjects" that only need to be kept informed.

Actors with high power but lower interests, the "context setters" in Figure II are the authorities. The authorities that are included here is the Dutch government. The national government has determined that NS is allowed to transport passengers on the most important rail routes, the so-called main rail network. The national government imposes requirements on NS to protect the interests of travellers. In contrast to the power of the authorities, the interest of authorities is quite low. They are therefore taken into account as actors that must be kept satisfied.

There are also three actors for whom both interest and influence are low: NS stations, interest organizations for the travellers and the parties that carry out the maintenance for Thales of what they cannot do themselves. All these parties do have interests. For example, the NS Stations department is responsible for the organization of stations, station resources also affect this. Interest organizations help travellers to get a good service from the NS and the parties that carry out maintenance for Thales are also part of the maintenance process. So adjustments to this will probably also have consequences for them.

In summary, it can be concluded from the actor analysis that the NS, Thales and the traveller are the main actors. The relationship between the NS and Thales in the maintenance of the station resources can be described as a principal-agent relationship. This is the relationship between the customer (principal), who pays for services or goods, and the agent. The principal is limited in his ability to monitor and judge the contractor's input and output. This leads to mistrust and can only be avoided under high monitoring costs (Keil, 2005). According to that the agent and the principal, not only have a common interest but also a self-interest, see also Chapter 2.1 for more information about this theory. In this case, the NS is the principal and Thales is the agent. The traveller is the user of the station resources. In Appendix 4 a description is given about these actors.

Description of the key players

The train traveller

This actor is the user of the station's resources. An average of 1,3 million people travel by train on an average working day (NS, NS Jaarverslag 2017, 2018). These people all have different nationalities, ages, destinations, travel purposes and physical comfort. It is therefore important that the station resources are easy to use and accessible to everyone. So elderly people who find technology difficult as well as people who are in a wheelchair need to be able to use the station resources without hindrance.

NS - Department BSM (management station resources)

N.V. Nederlandse Spoorwegen (NS) is the national railway company in the Netherlands. From 1938 to 1994, NS was the owner and manager of the Dutch rail infrastructure and operator of all transport services. In 1995, NS was privatized. It lost ownership and management of the rail infrastructure and the exclusive right to transport services by rail (separation of management and transport). In 2002, the infrastructure was formally transferred to the Ministry of Transport, Public Works and Water Management (Railpedia, 2019) (NS, NS Jaarverslag 2017, 2018).

The most important activities of NS at the moment are passenger transport by rail, hub development and construction (including the operation of stations). NS is a limited liability company under Dutch law with the sole shareholder being the Dutch State. The management and supervision are based on the structure regulation. The company is managed by a management and supervision takes place by a supervisory board. These organs are independent of each other. NV Nederlandse Spoorwegen is the holding company of NS Groep NV. The shares have been managed since 1 January 2005 by the Ministry of Finance (previously by the Ministry of Transport, Public Works and Water Management).

Within the NS you have the Station Resources Management department, which is part of IT Commerce & Development. This is where the development and management of complex IT systems take care of the resources at the stations. This includes ticket vending machines, counters, check-in posts, gates and Service and Alarm columns.

The mission of BSM is: "Station resources must be Discoverable, Reliable, Available, Manageable and Secure so that Customer satisfaction goes up and the Total Cost of Ownership is reduced" (NS, BSM).

Thales – Thales Transportation Systems

Thales Group is a French multinational company that designs and builds electrical systems and provides services for the aerospace, defence, transportation and security markets. It is partially state-owned by the French government and has operations in more than 56 countries. It has 65,000 employees and generated €15,8 billion in revenues in 2017. It is also the 10th largest defence contractor in the world and 55% of its total sales are military sales (Thales, 2019).

Thales Transportation Systems (TTS) is a subsidiary of Thales Nederland and had all the maintenance activities of the OV chip card system in the Netherlands under its management (Computable, 2003) (Pil, 2010). TTS customers are NS, RET, GVB, HTM, Qbuzz, Connexxion and Metro Amsterdam.

The mission of TTS is: "Together, we make a sustainable contribution to safe and attractive mobility in the Netherlands with innovative and reliable services and solutions, so that our customers can create more capacity within infrastructure, so that passengers can reach their destination faster, safer, more sustainably and at lower costs can reach" (Thales, 2019).

To achieve this, TTS offers a wide range of products and services for the transportation market. The TTS Service consists of services divided into four different categories:

- Life Cycle Services are services aimed at providing services to adjust, improve and extend the functionality of the system during and outside its lifespan in order to extend the life cycle and make systems future-proof.
- Maintenance Services are services for every type of system maintenance to maintain the quality, performance and functionality of systems, networks and infrastructure.
- Monitoring Services are services for real-time monitoring and monitoring of systems, networks and infrastructure to detect events and (possible) disruptions and to gain control and insight into the performance of the system.
- Operational Services are services for the operational day-to-day running of systems. Operational Services includes, among other things, the service desk, logistics and training services and the aim is to optimize the normal course of business and operation.

It differs per customer which services Thales delivers. For the NS, Thales delivers the Life Cycle Service and the Maintenance service. Monitoring is done by the NS itself, unlike the other transport companies, see Chapter 3, analogue maintenance studies and cases. This has arisen from history.

5. Service Levels Reactive Maintenance

(NS Groep N.V. & Thales Transportation Systems B.V., 2018)

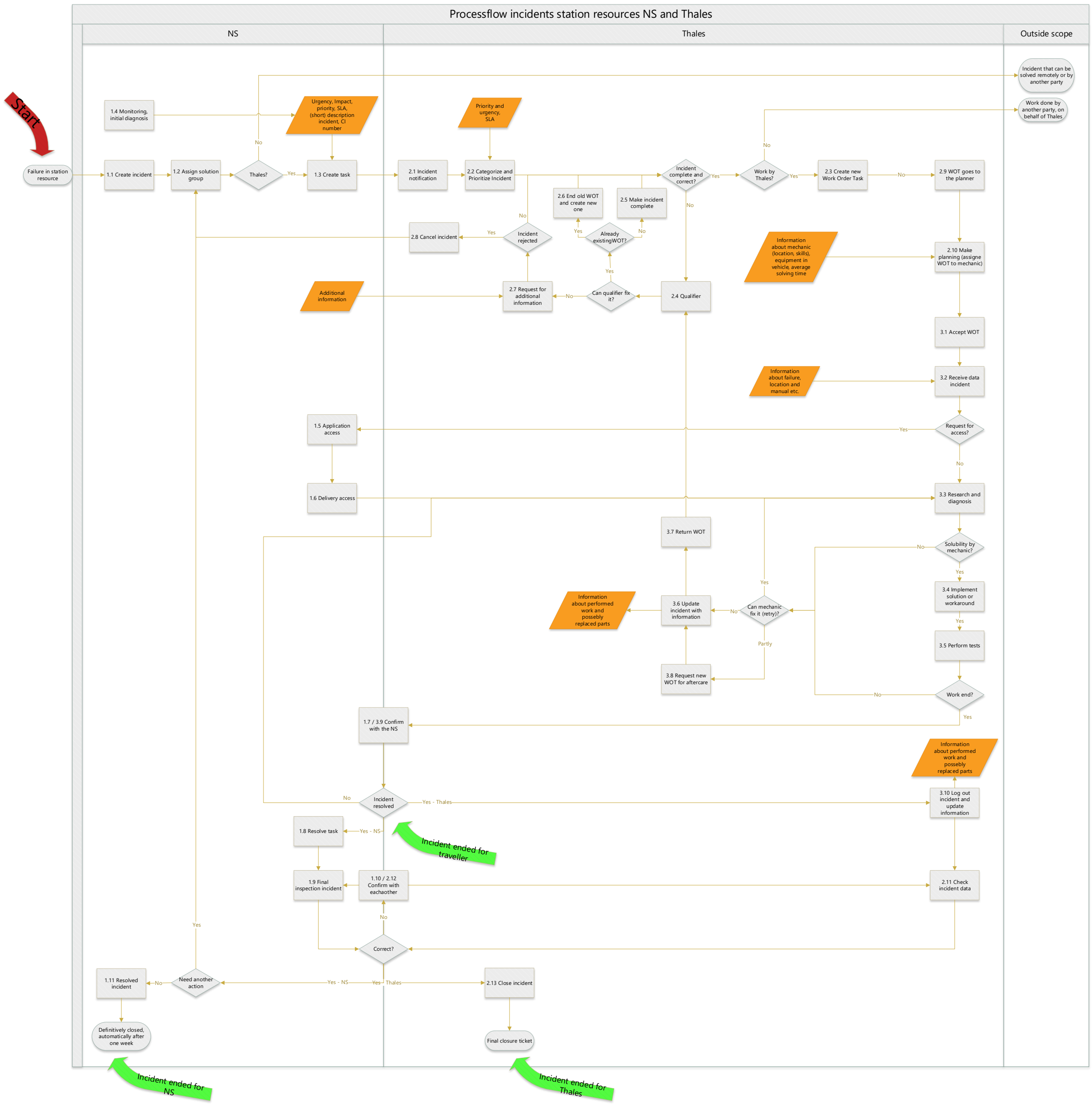
No.	Description	Equipment	Service Level	Service Window	Conditions
1	After Acceptance of the call, solve the Fatal and Urgent incident	Ticket sales equipment, OVCP equipment: Gates, Validators, NKZ, Emergency PLC/GEU units	95% < 4 hrs	7 days a week 06.00-22.00	Within Area A Service window closed during *Rush hours
				Working days 06.00-22.00	Within Area B Service window closed during *Rush hours.
				Weekend 09.00-17.00	Within Area B
2	After Acceptance of the call, create a safe situation for a Fatal and Urgent Incident	OVCP equipment: Glass Repair for gates, fixed barriers, doors and the repair of ramping's	95% < 4 hrs	7 days a week 07.00-21.00	Within Area A. Service window closed during *Rush hours
				Working days 07.00-21.00	Within Area B. Service window closed during *Rush hours
				Weekend 09.00-17.00	Within Area B.
3	After Acceptance of the call solve the Non-Fatal incident	Ticket sales equipment, OVCP equipment: Gates, Validators, NKZ, Emergency PLC/GEU units	95% < 72 hrs**	7 days a week 06.00-22.00	Within Area A. Service window closed during *Rush hours
				Working days 06.00-22.00	Within Area B. Service window closed during *Rush hours
				Weekend 09.00-17.00	Within Area B
4	After Acceptance of the call, create a safe situation for a Non-Fatal Incident	OVCP equipment: Glass Repair for gates, fixed barriers, doors and the repair of ramping's	95% < 72 hrs**	7 days a week 07.00-21.00	Within Area A. Service window closed during *Rush hours
				Working days 07.00-21.00	Within Area B. Service window closed during *Rush hours
				Weekend 09.00-17.00	Within Area B.
5	Repair after creating a safe situation	Glass Repair for gates, fixed barriers, doors and the repair of ramping's	Best effort	Working days 08.00-17.00	Service window closed during *Rush hours
6	Complete replacement of the object	Ticket sales equipment. OVCP equipment	Best effort	Working days 08.00-17.00	Service window closed during *Rush hours
7	After Acceptance of the call, solve the incident	OVCP equipment and Ticket sales equipment: NS HGB-IV, OTL and OTA test environment	Best Effort (<120 hrs**)	Working days 09.00-17.00	

* Rush hours are applicable on working days from 07:00 – 09:00 and from 17:00-18:30. During the Rush hours, the Service window is closed on specific stations. These stations and the equipment involved will be listed in the DAP.

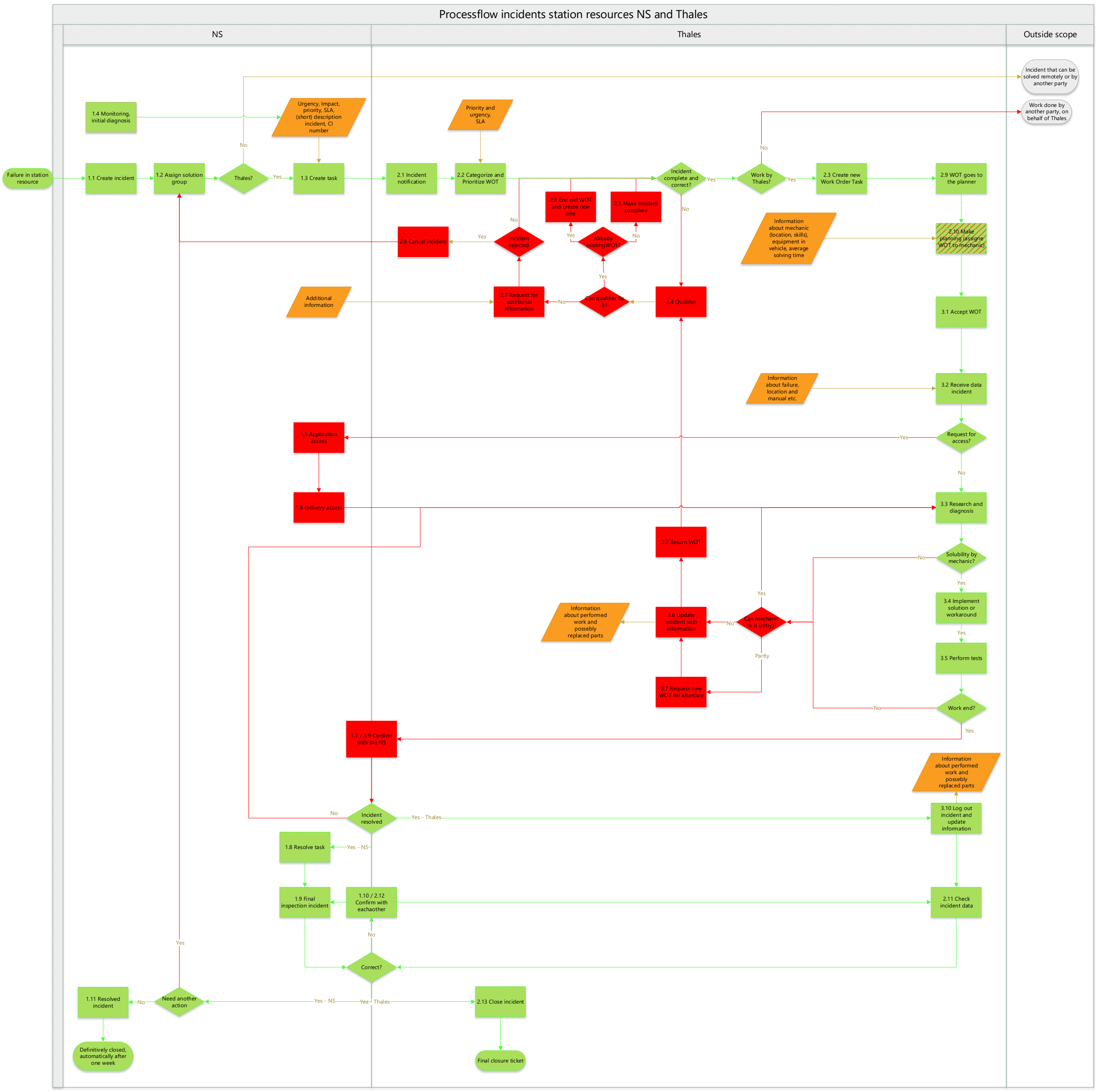
** The hours indicated have to be interpreted as un-interrupted 'clock' hours.

The Service levels of the reactive maintenance are different depending on the geographic location of the assets under maintenance. To distinguish between Service levels for Geographic locations, two areas are defined; Area A and Area B. Locations are placed in Area A or in Area B based on the demand for maintenance on the assets in the corresponding Area.

6. Process flow incidents of station resources NS and Thales

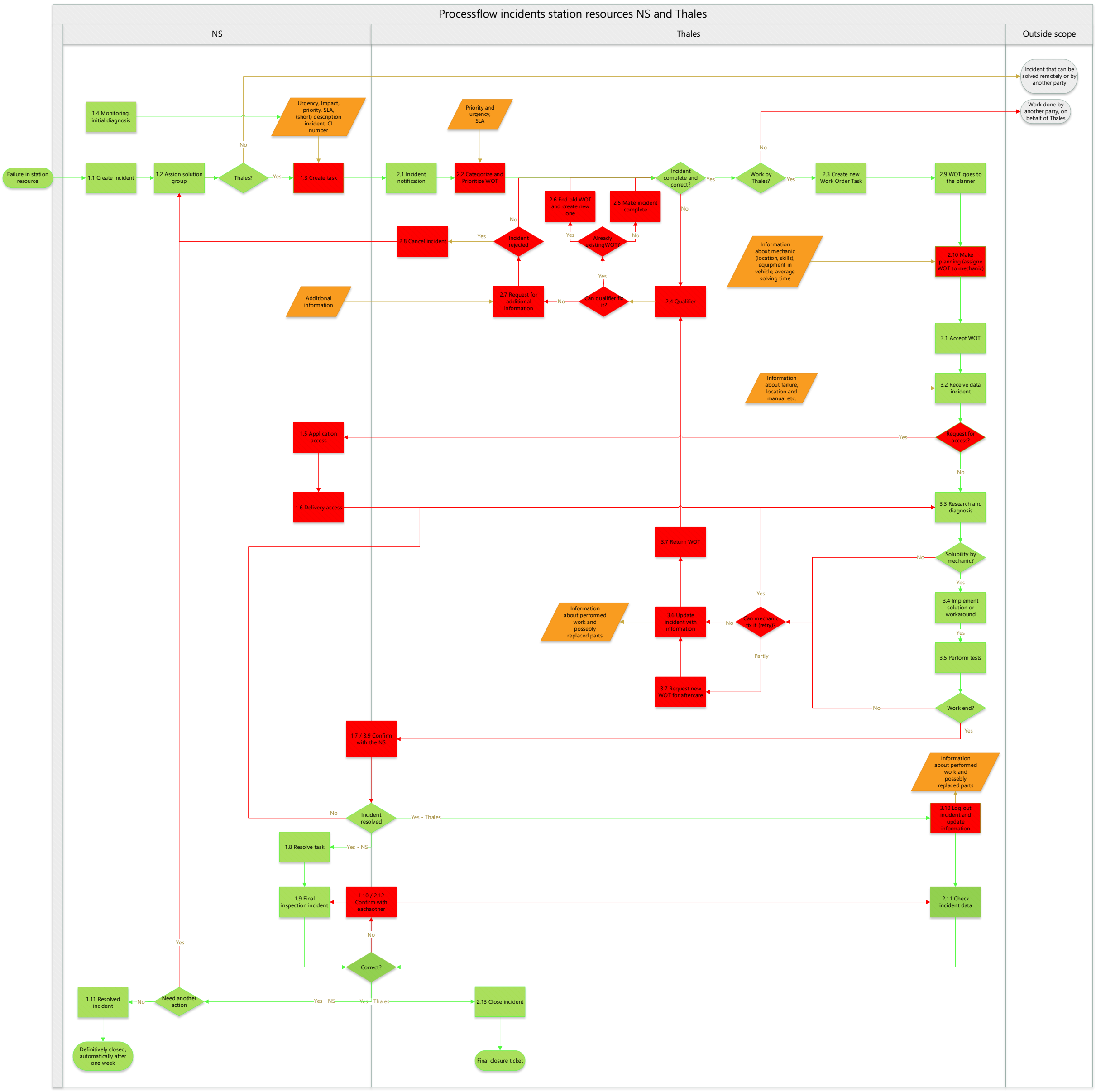


7. Impact on the process flow for the traveller

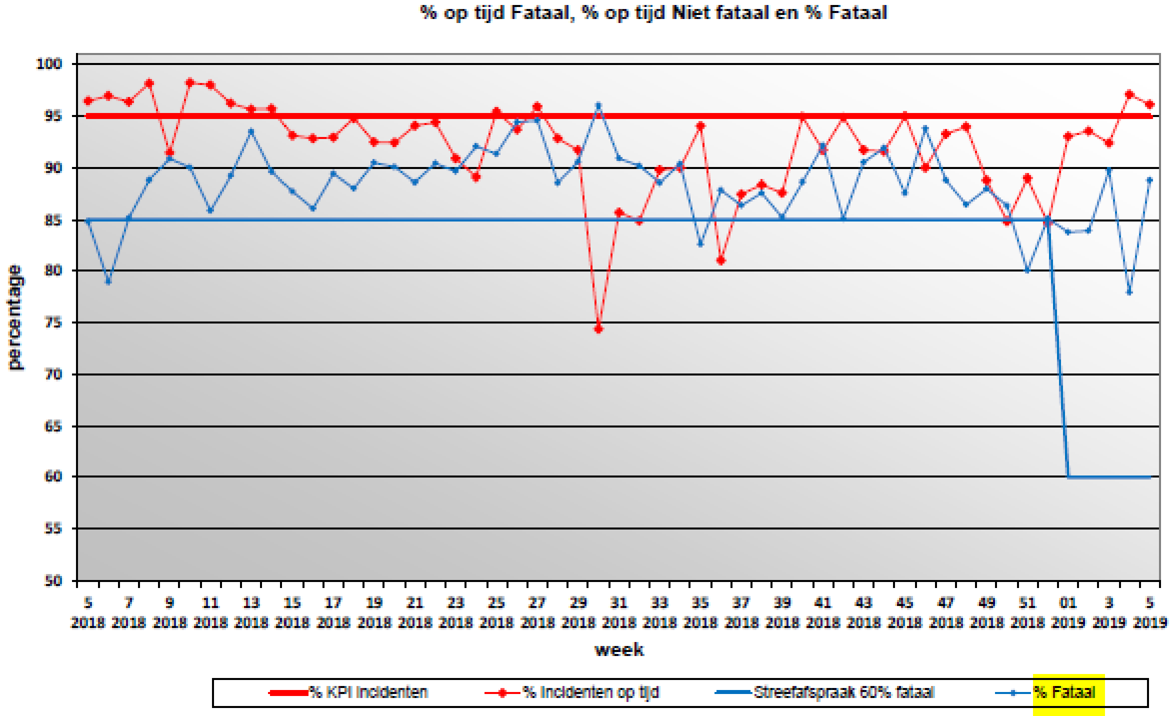


*Block 2.10 is not completely red, because the planner tries to make a planning, which ensures that failures are solved more quickly than without a planning. But it could be much more efficient than in the current situation.

8. Impact on the process flow for Thales and NS



9. Historical data about fatal vs non-fatal incidents 2018



10. Problem codes incidents Ticket Machines December 2018

	ET2006	ET2000
Not yet defined	1	0
(Main) Switch (s)	0	0
Connection	0	0
Operation button	0	0
Housing	1	0
Cabling	3	0
Decal	0	0
Payment terminal	24	6
Confirmation	0	0
MCU	14	2
Converter (glass/copper)	0	0
Door contacts	0	0
CTU Dispenser	29	-
CT Dispenser	64	-
Display operation	0	0
Display customers	0	0
Electronics (hardware)	0	0
Card reader (debit card)	47	7
Card reader (OV-chipcard)	-	1
ETT interface	3	0
ETT software	1	0
PKI SAM Dongel	0	0
PKI-sam	3	0
Fuses	0	-
Speaker	0	0
Micro switch	0	0
Coin cash register	1	-
Coin selector	123	-
Coin cassette	2	-
Router/switch/hub	1	0
Network	4	1
Sixnet	5	-
Out of paper	5	0
ADAM module	0	-
Printer	4	0
Paper transport	0	0
Sensor	0	0
Lock	1	0
Software Application	7	0
Software operating system	0	0
Touchscreen	11	1
Distribution unit	1	1
UPS/Battery	3	1
Lighting	0	-
Heating	0	-
Power supply(s-unit)	1	2
Coin dispenser	14	-
Quality paper	17	0
G4S	8	0
Retired by VAR	0	-

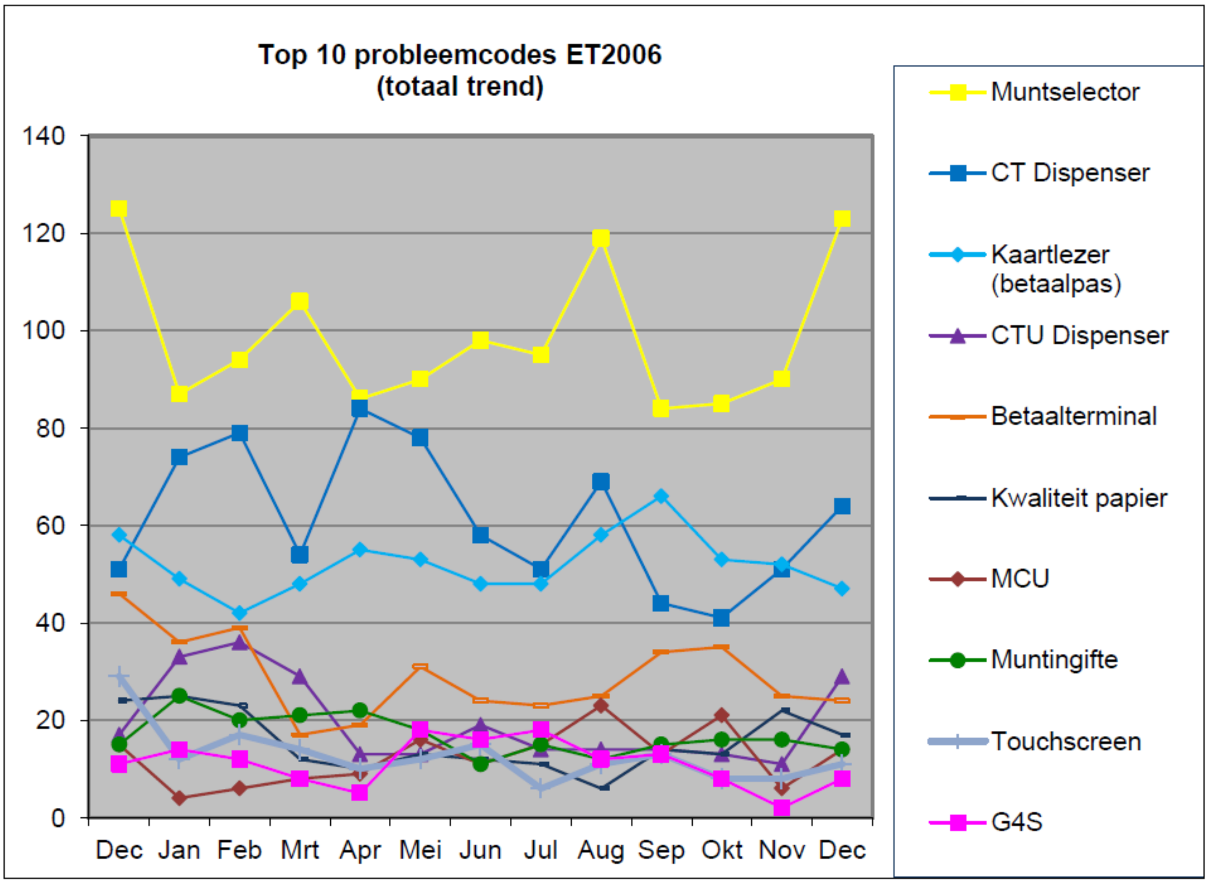
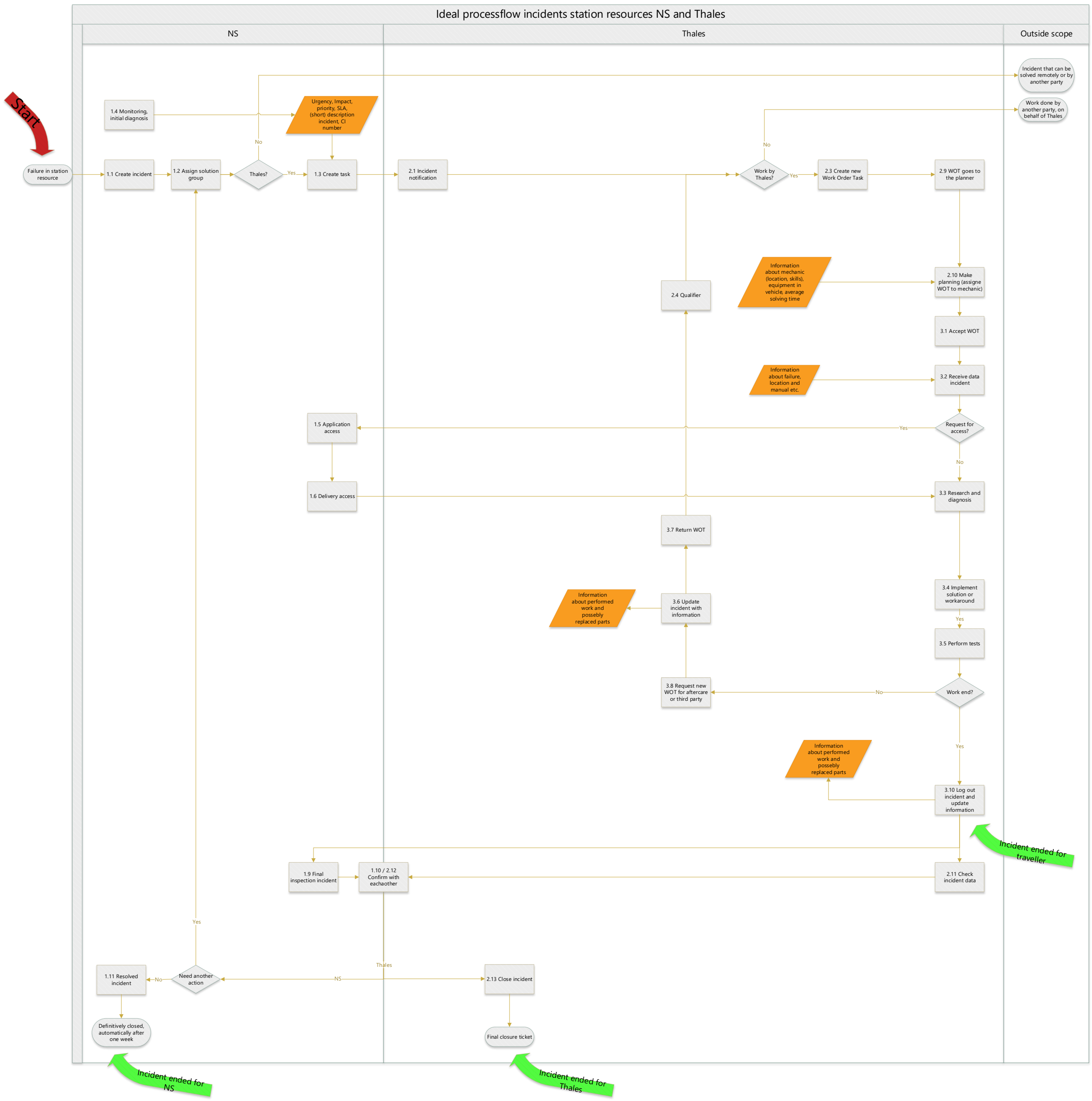


Figure III, Top 10 failure codes at the ET2006 in 2018

Table I, Incident solving codes December 2018

Solving code	ET2006	ET2000	LBS	CiCo	SA	Gates
Repaired with material	110	10	14	12	2	104
Repaired without material	240	6	28	20	18	295
No error found (tested, no reset)	28	6	10	5	0	40
Third parties involved	20	0	0	2	1	3

11. Preferred processflow incidents station resources NS and Thales



12. Scorecard explanation solutions

		# failures	# repeat failures	Equipment availability	Dissolution Time	Transportation and Staff Costs	Equipment Costs	Customer experience
1	Preventive maintenance	+	0	+	+	+	+	+
2	Predictive maintenance	+	0	+	+	+	++	+
3	Update CMDB more often or CI number check	0	0	+	+	+	0	+
4	If information is transferred or added manually, it is always complete and clear	0	0	+	+	+	0	+
5	Service Now Transparency	+	++	+	+	+	0	+
6	Demand-driven failure prioritisation- urgency	0	0	-	+ and -	-	0	++
7	Demand-driven failure prioritisation – actual failure	0	0	-	-	+	0	-
8	Planner Thales alert to repeat and combined failures	+	++	+	+	+	0	+
9	Periodically revised equipment in vehicle mechanic	0	0	+	+	+	0	+
10	Mechanics PTO independent	0	0	+	+	+	0	+
11	Score card third parties Thales	0	0	+	+	-	0	+
12	Score card mechanics	+	+	+	+	-	0	+
13	Avoid repeated process steps – no physical booklet	0	0	+	+	+	0	+
14	Avoid repeated process steps – less phone contact NS and mechanic	0	0	+	+	+	0	+
15	Avoid repeated process steps – mechanic can only close incident when complete	0	0	0	0	+	0	+
16	Full service contract type for all resources	+	+	+	+	+	+	+

General remark: it is a positive effect if the number of (repeat) failures decreases, the equipment availability increases, the dissolution time decreases, the transport and staff costs decrease, the equipment costs decrease and the customer experience increases. Because all this causes less inconvenience to the traveller or fewer costs for the Dutch Railways and/or Thales.

1. *# failures:* The number of failures will decrease as a result of preventive maintenance, which is a positive consequence for all main actors because reactive maintenance causes more nuisance than preventive maintenance. *# repeat failures:* The number of repeat failures will remain the same in relation to the current situation, as no measures have been taken in this solution to prevent repeated failures. *Equipment availability:* Because there are fewer disruptions, equipment availability will increase. *Dissolution Time:* When maintenance can be planned for the most part, the resolution time will be faster, because preventive maintenance always makes it clear what kind of work will be performed and a mechanic does not have to look for the cause of a malfunction. *Transportation and Staff Costs:* When maintenance can be planned for the most part, the division of work will be more efficient, so that more logical routes can be driven and staff can work at normal times. This saves costs. *Equipment Costs*: If preventive maintenance is done,

fewer things will fail in the equipment. This saves costs. *Customer experience:* Preventive maintenance can take place at favourable times, such as outside rush hour, which causes less inconvenience. In addition, the resolution time is also lower for preventive maintenance, making the customer experience more positive.

2. *# failures*: The number of failures will decrease as a result of predictive maintenance, which is a positive consequence for all main actors because reactive maintenance causes more nuisance than preventive maintenance. *# repeat failures*: The number of repeat failures will remain the same in relation to the current situation, as no measures have been taken in this solution to prevent repeated failures. *Equipment availability:* Because there are fewer disruptions, equipment availability will increase. *Dissolution Time:* When maintenance can be planned for the most part, the resolution time will be faster, because it is always clear for predictive maintenance what kind of work will be performed and a mechanic does not have to look for the cause of a malfunction. *Transportation and Staff Costs:* When maintenance can be planned for the most part, the division of work will be more efficient, so that more logical routes can be driven and staff can work at normal times. This saves costs. *Equipment Costs*: The equipment costs savings are even more positive with predictive maintenance because it is possible to determine more accurately when things break. *Customer experience:* Predictive maintenance can take place at favourable times, such as outside rush hour, which causes less inconvenience. In addition, the resolution time is also lower for preventive maintenance, making the customer experience more positive.

3. *# failures:* This has no changes compared to the current situation. *# repeat failures*: This has no changes compared to the current situation. *Equipment availability:* This becomes higher because the dissolution time is faster, so the equipment availability will also increase. *Dissolution Time:* Get faster because unnecessary process steps because of missing information are skipped. *Transportation and Staff Costs:* because unnecessary process steps are skipped, this saves labour costs. *Equipment Costs:* This has no changes compared to the current situation. *Customer experience:* The equipment availability and the dissolution time improve through this solution, so that gives a better customer experience.

4. *# failures:* This has no changes compared to the current situation. *# repeat failures*: This has no changes compared to the current situation. *Equipment availability:* This becomes higher because the dissolution time is faster, so the equipment availability will also increase. *Dissolution Time:* Get faster because unnecessary process steps because of missing information are skipped. *Transportation and Staff Costs:* because unnecessary process steps are skipped, this saves labour costs. *Equipment Costs:* This has no changes compared to the current situation. *Customer experience:* The equipment availability and the dissolution time improve through this solution, so that gives a better customer experience.

5. *# failures:* The number of failures will decrease as a result of more transparency within Service Now. Because there is more knowledge, disruptions can be prevented in the future. *# repeat failures*: Due to the transparency within service now, the repeat failures will decrease enormously, because it is previously detected that a CI fails again within a short time. *Equipment availability*: The equipment availability will improve because there will ultimately be fewer disruptions. *Dissolution Time:* The resolution time will also improve because the information pop-ups clearly indicate that a technician must first look at what solutions have already been implemented in the repeated failure so that he does not have to try them again. This saves time. *Transportation and Staff Costs:* Because there are fewer (repeat) disruptions, transport and personnel costs will also decrease. *Equipment Costs:* This has no changes compared to the current situation. *Customer experience:* The equipment availability and the dissolution time improve through this solution, so that gives a better customer experience.

6. *# failures*: This has no changes compared to the current situation. *# repeat failures*: This has no changes compared to the current situation. *Equipment availability*: This could decrease because it is possible that a gate in a row of 20 is out of order for a week because it does not cause any nuisance because there are still enough others present, but the availability does decrease. *Dissolution Time*: Can be better for failures with a high priority, but less for failures with a low priority. *Transportation and Staff Costs:* Can deteriorate for Thales, because different SLAs are going to get, but also SLAs with a short resolution time for high priority malfunctions, as a result of which the efficiency that Thales wants, through efficient routes etc, cannot be applied, so that the costs will increase. *Equipment Costs:* This has no changes compared to the current situation. *Customer experience:* This solution has the best effect on the traveller because it takes into account the prioritization of troubleshooting, which is very important to the traveller's experience. This is therefore very positive.

7. *# failures*: This has no changes compared to the current situation. *# repeat failures*: This has no changes compared to the current situation. *Equipment availability*: This will decrease because there are now fewer fatal failures compared to the current situation so that the resolution times become longer and the equipment availability decreases. *Dissolution Time*: This will decrease, because there are now fewer fatal failures compared to the current situation, the resolution times will be longer if only this aspect is considered. *Transportation and Staff Costs*: This has a positive effect because there are now fewer fatal disruptions compared to the current situation, Thales may take longer to resolve a disruption, making planning more efficient. *Equipment Costs:* This has no changes compared to the current situation. *Customer experience:* The equipment availability and the dissolution time deteriorate due to this solution, so that gives a poorer customer experience.

8. *# failures*: The number of failures will decrease as a result of more vigilance of the planner. *# repeat failures:* By improving the planner's attention, repeat failures are also expected to decrease enormously. *Equipment availability*: The equipment availability will improve because there will ultimately be fewer disruptions. *Dissolution Time:* The resolution time will also improve because the information will prevent pop-ups, repeated failures, but will also combine failures in a convenient way, resulting in efficiency that saves time. Transportation and Staff Costs: Because there are fewer (repeat) disruptions, transport and personnel costs will also decrease. In addition, malfunctions are combined and it is examined whether a mechanic must first pass a warehouse, so that 1 mechanics can solve 3 malfunctions of the same type on his own, instead of requiring 3 mechanics. *Equipment Costs:* This has no changes compared to the current situation. *Customer experience:* The equipment availability and the dissolution time improve through this solution, so that gives a better customer experience.

9. *# failures:* This has no changes compared to the current situation. *# repeat failures*: This has no changes compared to the current situation. *Equipment availability*: Because there is no need to create a new WOT because the necessary components are missing to resolve a malfunction, the equipment availability will improve. *Dissolution Time:* Because no new WOT needs to be created because the necessary components are missing to solve a malfunction, the resolution time will improve. *Transportation and Staff Costs:* Because a new WOT does not have to be created because the necessary components are missing for solving a malfunction, it is therefore not necessary for an additional technician to be involved to resolve the incident. This saves on transport and staff costs. *Equipment Costs:* This has no changes compared to the current situation. *Customer experience*: The equipment availability and the dissolution time improve through this solution, so that gives a better customer experience.

10. *# failures:* This has no changes compared to the current situation. *# repeat failures*: This has no changes compared to the current situation. *Equipment availability*: Because the dissolution time is faster, the equipment availability is also higher. *Dissolution Time:* Because the mechanic can be on site faster, the solution time will be shorter. *Transportation and Staff Costs:* Because the technician can be on site faster, the transport and staff costs will also decrease. *Equipment Costs*: This has no changes compared to the current situation. *Customer experience*: The equipment availability and the dissolution time improve through this solution, so that gives a better customer experience.

11. *# failures:* This has no changes compared to the current situation. *# repeat failures*: This has no changes compared to the current situation. *Equipment availability*: Because a scorecard often results in better performance, they will install parts that Thales cannot assemble themselves faster, making the equipment available again sooner. *Dissolution Time:* Because a scorecard often results in better performance, they will install parts that Thales cannot assemble themselves faster, which means that the malfunction can be completed faster. *Transportation and Staff Costs:* The third party is paid out on the basis of bonuses and maluses. If this incentive has the right effect and malfunctions that Thales cannot resolve itself are resolved faster, Thales will have to pay more bonuses, which will increase costs. However, they also get the SLAs from the Dutch Railways in this way, so that they earn bonuses, so that the costs are settled again. *Equipment Costs:* This has no changes compared to the current situation. *Customer experience*: The equipment availability and the dissolution time improve through this solution, so that gives a better customer experience.

12. *# failures:* Because mechanics often start doing better work because of a financial incentive to prevent repeat failures, the number of incidents will decrease.*# repeat failures:* The number of repeat failures will decrease because mechanics are assessed by a scorecard for, among other things, repeat failures after they have performed something. They will therefore want to prevent this, which will reduce the number of repeat failures. *Equipment availability*: Because a scorecard often results in better performance of the mechanic, they will solve the failure sooner, so the equipment availability is higher. *Dissolution Time:* Because mechanics often perform better because of a scorecard, they will resolve malfunctions faster. *Transportation and Staff Costs:* The mechanics are paid out on the basis of bonuses and maluses. If this incentive has the right effect and malfunctions are resolved faster, Thales will have to pay more bonuses, which will increase the staff costs. However, they also get the SLAs from the Dutch Railways in this way, so that they earn bonuses, so that the costs are settled again. *Equipment Costs*: This has no changes compared to the current situation. *Customer experience*: The equipment availability and the dissolution time improve through this solution, so that gives a better customer experience.

13. *# failures:* This has no changes compared to the current situation. *# repeat failures*: This has no changes compared to the current situation. *Equipment availability*: Because repeated processes are eliminated in this solution, dissolution time will decrease, which will increase equipment availability. *Dissolution Time*: Because repeated processes are removed in this solution, the mechanic will be able to complete the failure faster. *Transportation and Staff Costs:* Because repeated processes are eliminated in this solution, the staff costs will decrease. *Equipment Costs:* This has no changes compared to the current situation. *Customer experience*: The equipment availability and the dissolution time improve through this solution, so that gives a better customer experience.

14. *# failures:* This has no changes compared to the current situation. *# repeat failures*: This has no changes compared to the current situation. *Equipment availability*: The equipment availability will improve because a process step is removed, so that the mechanic can do his job faster and the equipment is therefore available again sooner. *Dissolution Time:* The dissolving time will also

improve because a process step is removed so that the technician can do his job faster. *Transportation and Staff Costs*: Because the technician can work faster, the personnel costs will eventually fall. *Equipment Costs*: This has no changes compared to the current situation. *Customer experience:* The equipment availability and the dissolution time improve through this solution, so that gives a better customer experience.

15. *# failures:* This has no changes compared to the current situation. *# repeat failures*: This has no changes compared to the current situation. *Equipment availability:* This has no changes compared to the current situation. *Dissolution Time:* This has no changes compared to the current situation. *Transportation and Staff Costs*: Because repeated processes are eliminated in this solution, the staff costs will decrease. *Equipment Costs:* This has no changes compared to the current situation. *Customer experience*: In principle, the traveller does not notice much of this solution. However, now that processes are running more efficiently behind the scenes, the staff has more time to analyse the malfunctions, so there will be fewer malfunctions and they will be resolved faster. Which ultimately has a positive effect on the customer experience.

16. *# (repeated) failures:* The full-service contract will make Thales' behaviour more efficient, which means there will ultimately be fewer (repeated) failures. *Equipment availability:* If there are fewer failures, the equipment availability will also increase. *Dissolution Time:* Due to the full-service contract, Thales will carry out more and more planned maintenance, which means a shorter resolution time. *Transportation and Staff Costs:* Because Thales is more forced to act more efficiently, transport and staff costs will also fall. *Equipment Costs*: The equipment costs will fall due to the expected preventive and predictive maintenance. *Customer experience*: The equipment availability and the dissolution time improve through this solution, so that gives a better customer experience.

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