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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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). 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.

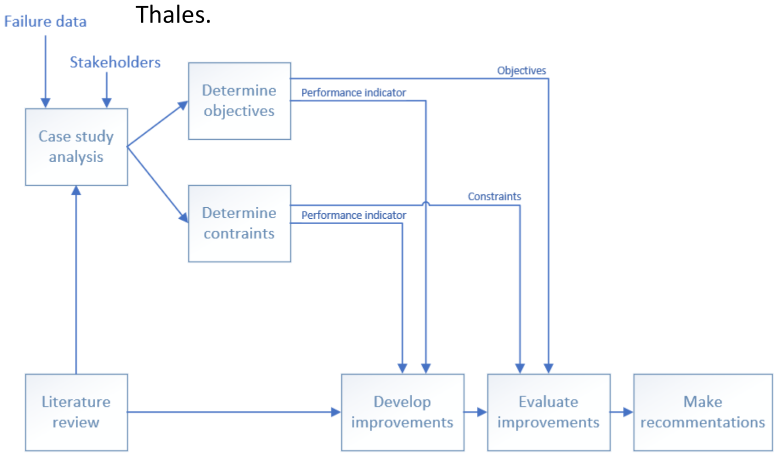

Figure A, Methodological framework, based on the metamodel of design (Herder & Stikkelman, 2004)

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).

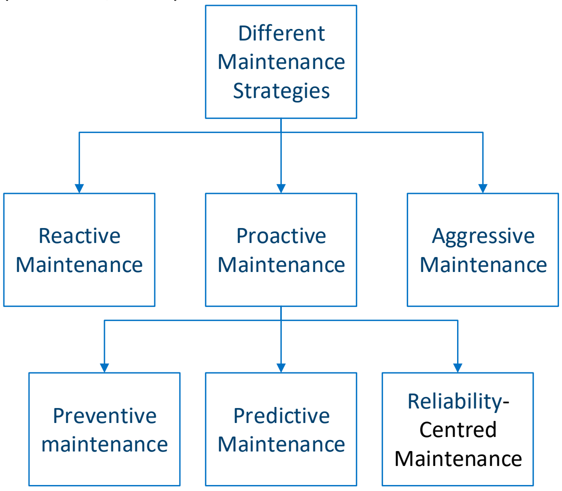

Figure B, Overview maintenance strategies

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, 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.

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.

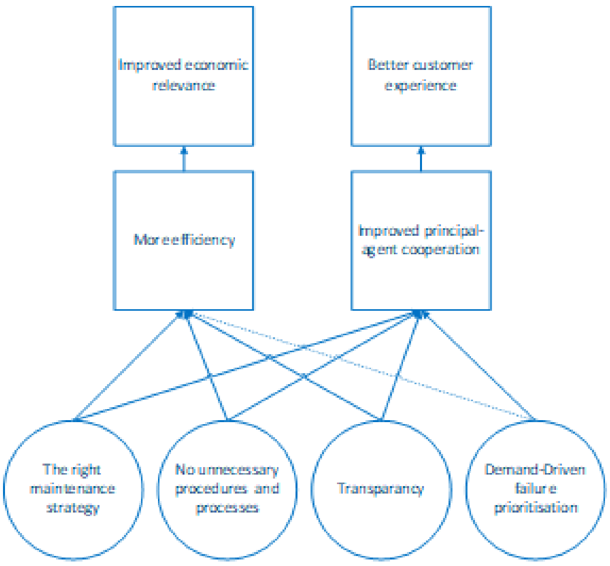

Figure C, Concluded relation between scientific concepts

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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