



ENLARGING THE CLEANING CAPACITY OF THE NS

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NS

Preface

Before you lies my thesis “Enlarging the cleaning capacity of the NS”. This thesis forms the finalization of the bachelor Industrial Engineering and Management at the University of Twente. As the name indicates this thesis is about creating more cleaning capacity for the NS. The main focus is on shifting the cleaning activities from night to day and by doing that creating more capacity. This research is executed at the department “Landelijk Bureau Reiniging” of the NS.

I would like to take this opportunity to thank the NS and especially Peter Goorden for the research topic. During this research period the NS gave the operating space to choose the direction of my research. The most important aspect for me was the practical implementation of this research assignment. The NS is really in the need of an enlarged cleaning capacity. Because of this the research was much more relevant. Various experiments are performed to validate the possibilities of cleaning at day time. This relevance and the urgency of the problem gave me the energy to work on the solution.

Even after this research period, the NS will go on performing research and experiments on this topic. Their goal is to shift the cleaning capacity from night to day and with that creating an enlarged cleaning capacity. I am proud to say that I have contributed to the first steps in this big switch towards the solution for the NS.

The NS is a huge company and their working environment is quite individualistically. This gives a lot of operating space, but it took some time to get used to this working environment. Nevertheless, everybody always took the time to answer my questions or help me with my research. I want to thank especially Peter Goorden for always being available to answer my questions.

Furthermore, I want to thank my supervisor from the University of Twente, Ipek Seyran Topan. I have never seen someone answering my mails so fast. Every question could be asked, it was really nice and helpful to have her as my supervisor.

Last but not least, a big thanks to my family, friends and girlfriend for their support!

I hope you will enjoy reading this thesis!

Jesse Verduijn
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Management summery

NS is the biggest public transport company of the Netherlands. The majority of the dutch citizens knows the NS. NS transports daily more than one million people. As you can imagine every traveler would appreciate a clean train. Currently, every day about 5% of the trains can not be cleaned because of a lack in the cleaning capacity. The NS norm is to clean a train every day after its last run, before the start of its first run the following day. So, currently one out of twenty trains will start their first run without being cleaned. The use of the NS trains is growing and the NS will need more and more trains. This will make the problem grow even further. It is important to the NS to maintain their quality levels and sattisfy their customers. Therefore, the problem is urgent and the NS is working towards an alternative to increase the cleaning capacity.

The problematics in the cleaning capacity are caused by a peak in the workload. The group of trains that is causing that peak is called the target group. The research will focus on lowering the peak in the workload and therefore tackling this target group.

There are multiple ways to create more cleaning capacity. Right now, the cleaning activies of the NS are only performed by night. The vision of the NS is to create more capacity by shifting the cleaning activities from night to the day time. This is also where the focus of this research will be. The research question is: *“What are the possibilities of cleaning trains by day and their effects on the capacity by night?”*.

In this research the effect and possible implementation of two solutions will be worked out. The first solution is about using the current daily excess of the trains. Currently, not every train is running the whole day, some trains are standing still long enough to clean them. This is called “the daily excess”. The second solution is an extension of the first solution, the goal is to create even more possibilities to clean the trains in daytime.

This research is a study on the timetable of the NS. The results of this research will show the potential of cleaning in daytime for both solutions. The following questions will be answered:

- How many trains can be cleaned in daytime?
- What are the potential cleaning locations?
- What is the effect on the peak in the workload?

The function of this research is to show the possibilities. What is possible and which benefits can be gained? Answering this question shows the NS if it is worth the effort to make this big change.

This research shows that averagely, from Monday to Friday, 27.4% of the trains of the target group have a cleaning possibility in day time. Due to several constraints it is not possible to clean all of these trains in day time. With these constraints taken into account this research shows that averagely, from Monday to Friday, 10.2% of the trains of the target group can be cleaned in day time.

This are promising results and currently the NS is starting to clean trains in day time at several pilot locations to test the feasibility and effects of cleaning in day time.

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List of definitions and abbreviations

- *HRS*
Hago Rail Services, a company that performs the cleaning activities for the NS.
- *Dirty starter*
A train that could not be cleaned during the night and therefore has to start its first ride dirty.
- *VBA*
Visual basic, a programming language in Excel. This can be used to create several useful tools for analyzing data.
- *KPI*
Key performance Indicator, an important variable with which the performance is measured.
- *Cleaning location*
A location where HRS performs cleaning activities.
- *Task package of cleaning a train*
For every train there is a list of elements that need to be cleaned. This is called the task package of cleaning a train.
- *Maximo*
An application that the HRS personnel use to communicate and to handle the administration.
- *PowerBi*
An application that NS uses to display several key performance indicators.
- *End time*
The time that a train is done with performing the last run of the day.
- *Target group*
Trains with an end time between 00:00 and 4:00

A general note

In this report, a 24-hour clock is used, 22:00 =10:00 P.M. and 10:00 = 10:00A.M.

Introduction

This chapter is an introduction to the research topic. Chapter 1.1 gives a description of the company and its structure. Chapter 1.2 describes the LBR department and their corresponding activities. Chapter 1.3 elaborates the problem that the research focusses on. Chapter 1.4 states the main and sub questions and the problem-solving approach. The last part, chapter 1.5, is about the scope of this research. Several meetings with the client and HRS (Hago Rail Services) gave knowledge and a deeper understanding of the organization and the problem. The information in this chapter is based on these meetings and several expert opinions.

1.1 Company description

The NS is the biggest public transport company of the Netherlands. Every day NS transports over 1.000.000 people with almost 3.000 train sets. They stimulate the use of public transport and have a huge responsibility regarding the Dutch mobility. The NS strives to transport their customers as comfortable and sustainable as possible. The traveler is NS their priority number 1, 2 and 3.

The Dutch government has a 51% share in NS. Because of this, the government is the one in control. The government signed a contract with the NS. This contract states that the NS is responsible for the Dutch public transport system. Right now, May 2019, they are on the mid-term of the contract. The contract is valid from 2015 to 2025. The rating at the midterm contract is important, because this is considered while deciding if the contract will be extended at the end of 2025.

The NS consists of various departments. To get some more insights in the structure of the organization an organogram of NS is shown in appendix A.1. This research is done at NedTrain department. NedTrain is responsible for the cleaning, overhaul and maintenance of the trains. NedTrain also consists of various departments, see appendix A.2. Within NedTrain this research is performed in favor of the department “Landelijk Bureau Reiniging (LBR)”, in English “National Office of Cleaning”. This department is responsible for internal and external cleaning of the trains. In the organograms, the boxes of NedTrain and LBR are marked green.

1.2 LBR

As mentioned before, LBR takes care of the internal and external cleaning of the NS trains. Most of these activities are performed at night.

The external cleaning can be subdivided into three categories.

- *Graffiti cleaning*
If a train is polluted with graffiti, a special team of cleaners will remove the graffiti within a few days. Sometimes, the graffiti creatures contain offending texts or paintings. In this case, the train will be cleaned at the end of its ride.
- *Cleaning after an accident with a living being.*
After such an incident a special team will clean and disinfect the train. This cleaning activities are only performed at one location in the Netherlands, the emergency hall at Amsterdam Zaanstraat.
- *Train washing installations*
Every week a train must be cleaned in a train washing installation. Once in a two-month period the trains will be cleaned more intensively.

This research is focused on the internal cleaning of the trains. The internal cleaning can be divided into four categories:

- *Urgent*
If a train needs to be cleaned urgent, the norm is to clean this train at the first big station. These trains are cleaned within two hours in 95% of the cases. In appendix B.1 a list of criteria to label a train as “in the need of urgent cleaning” can be found.
- *Daily cleaning of trains*
To maintain the cleanliness level of the trains, every train that transports at least one person will be cleaned by night.
- *Care on track*
During a ride, HRS personnel cleans the train. While the train is running not every cleaning activity can be performed. So, only the biggest dirt/trash is cleaned. Nevertheless, it does have a positive effect on the customer satisfaction and travelers are less inclined to pollute these trains. This is because of the visibility of the cleaning personnel.
- *Short cleaning at the turning point of a train*
This is done to maintain the quality levels of the cleanliness of the trains during the day.

Within the internal cleaning, this research will go in depth on the daily cleaning. To get more insights in the daily cleaning of the trains this process will be described in chapter 2.

The cleaning process takes place at 45 locations through the Netherlands, a list with these locations can be found in appendix B.2. Trains can be cleaned only at a cleaning track. This is because of several constraints regarding safety and working conditions. All activities regarding the daily cleaning of the trains are currently performed by night.

To clean the trains, the NS has a contract with HRS. HRS is responsible for cleaning all the trains that can and need to be cleaned. The NS pays HRS a fixed amount of money to clean the trains. Because of this, HRS tries to minimize staff hours in order to create a higher profit. Of course, HRS strives to deliver the desired quality. But, the less people are needed, the higher their profit. The personnel of HRS works in shifts, from approximately 22:00 to 6:00. Dependent on the location and their spread of the workload, shifts can start a bit earlier or later. Further on in this research it will be described as if all shifts start at 22:00 and end at 6:00, keep in mind that this can vary a bit per location.

To measure the performance of the current process and HRS, NS handles 5 Key Performance Indicators (KPI's).

- *Percentage of trains that are completely cleaned*
This KPI measures the performance of the whole cleaning system and is calculated by:
(The amount of trains that are cleaned / The amount of trains that should be cleaned)
- *Percentage of dirty starters*
The percentage of dirty starters is calculated by:
(1- (The amount of trains that are offered to HRS for cleaning / The amount of trains that should be cleaned)).

- *The amount of trains that are offered for the cleaning process.*
This KPI measures the volume of cleaning activities that have to be performed by HRS
(Total amount of used train sets - The dirty starters)

- *Percentage of the cleaning elements of category 1 that meet the quality restrictions.*
This KPI makes the cleanliness level of the train measurable and is calculated by:
((The number of elements in category 1 that are cleaned well / Total amount of elements in category 1) / Train sets that are offered to HRS)

- *Percentage of the cleaning elements of category 2 that meet the quality restrictions.*
This KPI makes the cleanliness level of the train measurable and is calculated by:
((The number of elements in category 2 that are cleaned well / Total amount of elements in category 2) / Train sets that are offered to HRS)

The cleaning elements of category 1 & 2 can be found in appendix B.3.

A train is labelled as clean if it meets all the quality requirements before the start of its shift. To check if the cleaning personnel (HRS) is respecting the quality demands, there are several inspectors. These inspectors check if trains are cleaned according to the agreements. Based on these random checks, NS assesses the performance of HRS.

1.3 Problem description

Currently, the use of public transport is growing. With that, the use of the NS trains also grows. NS is using more and more trains to handle the grow in the use of their service. This also results in the fact that more and more trains need to be cleaned.

Right now, there is a lack of capacity to clean the trains. Because of the grow in the use of public transport, this problem will only get worse if nothing changes.

The lack of capacity is caused by an unevenly divided workload. The cleaning personnel of HRS has to deal with peak hours and calm hours. Roughly said, the first and last two hours of a shift are calm hours (22:00 to 00:00 & 4:00 to 6:00). The hours from 00:00 to 4:00 are peak hours. This is because, after 00:00 most trains arrive at their end station and are ready to go into the cleaning process. From there trains can be offered to HRS for cleaning. Offering a train for cleaning means, parking the train at a cleaning track so that HRS is able to clean the train. At 4:00 most trains start running again. This causes a peak in the workload between 00:00 and 4:00. During the peak hours the workload exceeds the capacity of the HRS cleaners. During the calm hours, the cleaning capacity higher than the workload. To clarify the distribution of the workload, a rough sketch of the capacity and the workload against time is displayed in figure 1.

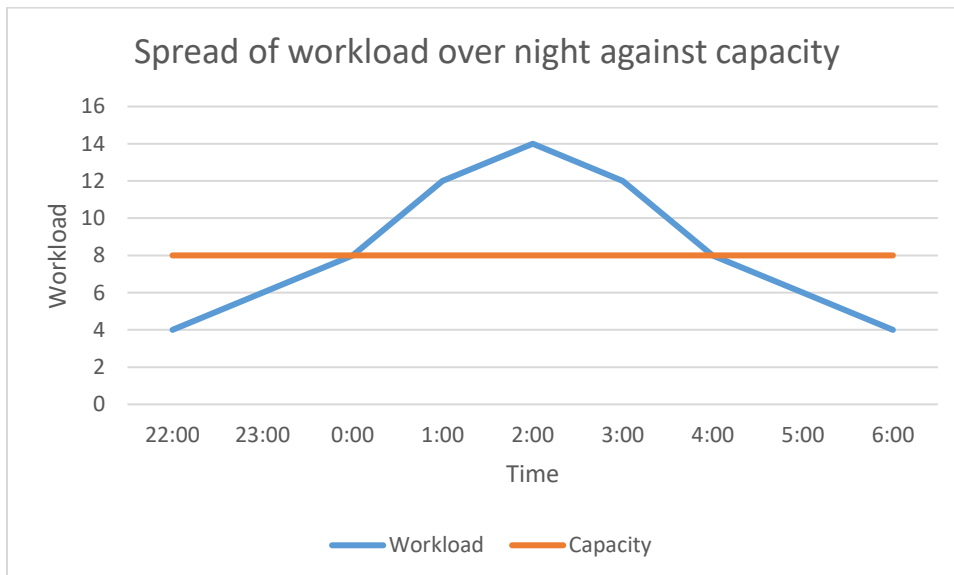


Figure 1: Spread of the workload

Right now, the norm of the NS is that every train, that transports at least one person, is cleaned once a day every night. Because of the capacity problem, this norm is not the same as the reality. Not every train can be cleaned by night, which causes dirty starters.

To summarize, the problem is that during the peak hours, the workload exceeds the cleaning capacity. To solve this problem either the capacity can be increased, or the workload can be spread in a better way. Since the timetable cannot be adjusted, there are basically four options to tackle this problem.

- *Reduce the task package of cleaning a train*
For every train there is a list of elements that need to be cleaned during these cleaning process. All the tasks performed to do so is called the “task package of cleaning a train”. If the list of elements that need to be cleaned is shortened or less intensive, this task package lowers. This will cause a drop of the total workload. So, by doing this, the workload as well as the capacity exceedance will drop.
- *Shift the (exceeding) workload to another time period*
If the workload during the peak hours can be scheduled in another time interval, capacity exceedance will drop and the workload by night will be more evenly divided.
- *Improve the efficiency of the current cleaning process*
Improving the efficiency of the current cleaning process, directly results in a higher overall capacity to clean trains. Because of the increased capacity, the capacity exceedance will drop.
- *Hire more personnel*
More personnel can handle a higher workload.

Unfortunately, not every option is feasible and therefore there are some difficulties in growing this capacity:

- *Hiring more personnel is limited*
According the schedule manual, HRS needs to offer shifts of at least 4 hours to their personnel. In reality, this is not feasible. Some personnel does not show up at shifts of 4 hours, especially in the middle of the night. This causes uncertainty. Therefore, HRS only works with shifts of approximately 8 hours. Because of the peak hours, it is too expensive to schedule personnel for the whole shift at the highest workload.

Another aspect that contributes to this bottleneck, is the schedule manual. In this manual there are limits of scheduling people by night. A full timer works 18 shifts a month and only a maximum of 12 shifts may be scheduled as night working shifts. So, while hiring a full timer 1/3 of the working activities must be performed by day. Therefore, hiring more personnel for only night work is inefficient and costly.

Also, trains cannot be treated at every track. Maintenance and cleaning activities of trains must be done at cleaning tracks. There only is a limited amount of these tracks available, which causes a bottleneck in the system. If there are more trains available then cleaning tracks, trains will have to wait to be cleaned. Also, there is a limit in cleaning staff per train. More people cleaning a train does not result in an evenly declining cleaning time for the train. Therefore, scheduling more personnel does not directly result in an evenly improved capacity. Because of that, scheduling personnel is limited even more costly and solves this problem only partially. Building more cleaning tracks is very expensive and takes a lot of time. The problem is urgent and therefore building more tracks takes too long.

Shortly, solving this problem by scheduling more personnel is too expensive.

- *Problems of improving efficiency in the current situation*

As mentioned before, the amount of trains the NS uses is growing. Accordingly, capacity to clean trains should be gained. The NS is already working on this by improving the efficiency of the cleaning process. Unfortunately, the amount of trains grows faster than they can grow the capacity this way. This solution only makes the situation less bad and does not solve the problem.

- *Problems in reducing the task package of cleaning a train*

The NS created their cleaning standards with a reason. For example, cleaning standards are created in a way that a train can be used for a X amount of years, varying per train category. Therefore, the task package may not be lowered, and this is not a feasible solution.

- *Obstacles in shifting the workload*

At first, it seems the most logical to spread the workload from the busy hours to the calm hours in the night shift, but this would require a change in the timetable. This change would be too big and is therefore not feasible. As mentioned, all the cleaning activities regarding the daily cleaning of trains are performed at night. This is a huge limitation in the current situation. Certain KPI's are adjusted to the current situation. Eliminating the limitation of only cleaning by night may enable a lot of potential solutions in solving the capacity problem. Still, the KPI's are another limiting factor of the current situation. A train that is cleaned in daytime, also must be cleaned by night in order to not become a dirty starter. So, letting go of these KPI's and adjusting them in the favor of a possible solution would enable more possibilities. For example, with the new constraints it could be that a train will be labeled as a "dirty starter" if it is not cleaned for the last 24 hours.

Right now, trains are only cleaned by night. This is because, at first it seemed the easiest and best way to do so. Nevertheless, there is need for a shift right now. Starting to clean in daytime enables new possibilities and a higher cleaning capacity. The only downside so far, the NS does not have any insight in the effects of cleaning trains by day.

So, to be able to handle the workload, now and in the future, the only long-term solution seems to be to start cleaning trains in daytime. Currently, the effects and possibilities of cleaning trains in daytime are unknown. So far, this knowledge is not obtained. This is because there was no need to do so. Obtaining knowledge on the possibilities of cleaning in daytime and the effects on the capacity by night, is where this research focusses on.

Due to several complications, the effects and possibilities of cleaning by day are very difficult to map. These complications are listed below:

- *Peak hours*

If a train that would normally be cleaned during the calm hours is cleaned by day, it is not beneficial. Instead, it is only beneficial to clean trains by day if this lowers the workload during the peak hours. This causes complexity. Cleaning a train by day does not necessarily result in a higher capacity. Therefore, it is necessary to know where and at what time a train ends that is cleaned by day. Only if the end time of the train is during the peak hours, it is beneficial.

- *Uncertainty in the end station of trains*

For the logistics of the trains, NS has a year planning, a two-month planning and a daily planning. The year planning is made at the start of the year and should hold for the whole year. Of course, this is not possible due to for example maintenance of tracks. Therefore, every two months a planning for the coming two months is made. Daily unexpected events occur, like vehicle accidents with living beings. For this reason, there is a department that adjusts the planning on a daily basis. Because of the daily last-minute adjustments in the logistics, there is an uncertainty in the end stations of trains. Because of this uncertainty, it is very difficult to predict which cleaning locations will benefit at night.

- *Lack of research and implementation*

Currently, no experience or information is available on the possibilities and the effects of cleaning by day on the capacity by night.

To visualize the problems and its causes, a problem cluster is designed. The problem cluster can be found in appendix C. This research will focus on filling the gap in the lack of information of the effects of daily cleaning. Filling this information gap gives NS insights on the different solutions and how to solve the capacity issue. The corresponding box in the problem cluster of the problem that this research will solve, is marked green.

1.4 Main questions, sub questions and problem-solving approach

As mentioned before, the only long-term solution is shifting a part of the cleaning activities to daytime. The problem to tackle is the lack of information. With data analysis and experiments, the possible solutions and their effects will be investigated. The research question of this research is “*What are the possibilities of cleaning trains by day and their effects on the capacity by night?*”

This research question is divided into four sub questions:

- What does the current situation look like?
This question will be answered in chapter 3
- What are the possibilities and what is their potency on improving the capacity by night?
This question will be answered in chapter 4
- How to use the possible solutions optimally to lower the workload during the peak hours?
This question will be answered in chapter 5

What does the current situation look like?

To solve the problem in the current situation it is important to know how this situation looks like. This is where the research starts with. To map the current situation, data needs to be gathered and analyzed. A lot of data is already available. The goal of this part of the research is to get knowledge about the current situation, its performance and to get more insights in the cleaning process. To do so the following sub questions need to be answered:

- *What does the cleaning process look like?*
To get more insights and more feeling with the process of cleaning a train a marshalling yard, where cleaning activities take place, will be visited during daytime. The marshalling yard will be observed, to get to know how it looks and how it is controlled. In daytime there are no activities regarding the daily internal cleaning of trains, but other activities like graffiti cleaning are performed. The visit is a tour through the process. My guide will tell about the process and the personnel there will shortly tell what their job is. Also, there will be the opportunity to ask further questions to these personnel.

These moments will be used to get additional information on the system, to make sure the system is understood properly. Apart from that there is a lot of data available of how the cleaning process theoretically looks like. This information combined with the experience at the marshalling yard will be used to sketch the cleaning process

- *How does the current process perform?*

The process is measured by various KPI's. This data will be used to show the current performance of the system. The negative side, the KPI's are set for the current situation. While implementing a solution, most likely, some KPI's will be changed for this new situation.

- *Is the problem as described?*

The start of the research will be about the verification of the problem. NS and their cleaning partner provided information about the problem. This part of the research is to get to know if these insights are right and to make the problem concrete. This will be done by analyzing the timetable of NS.

What are the possibilities and what is their potency on improving the capacity by night?

The second step is to seek solutions and to investigate their potency. In order to answer this question, the following sub questions will be answered:

- *What are the possibilities?*

At NS multiple people are working on the capacity issue. Several meetings are arranged to share thoughts. This way, information about potential solutions can be shared.

- *What is the potency of the discussed possibilities?*

Insights will be created by experiments and an analysis of the timetable of June 2019. The analysis of the timetable is a theoretical study. The intended outcome of the experiment(s) is mainly verification on the feasibility of the theoretical solutions.

- *How reliable is the planned logistics compared to the realized logistics?*

Most of the effects and possibilities are based on an analysis of the timetable. Therefore, it is important to know how reliable the timetable itself is.

How to use the possible solutions optimally to lower the workload during the peak hours?

With all possibilities and their potential known, the implementation of this possibilities and the results of the implementation will be investigated. To do so there are two sub questions:

- *How to implement the different possibilities?*

For every possibility the potency known, since this is done in the previous step. Still, the implementation is unknown. For example, which trains will be cleaned and at which stations? Choices have to be made in order to come up with an implementation strategy. Based on several choices and constraints an implementation strategy will be created. The constraints will be set in consultation with NS and HRS.

- *What are the effects of the implementations?*

After the implementation strategy is prepared, the corresponding effects will be worked out. This will be done by an analysis of the timetable.

Deliverables

The deliverables that will be produced during the research are listed below:

- Analyses of the current situation
- Possibilities in shifting the workload during the peak hours to daytime
- The effects of the different solutions
- The implementation of the different solutions
- The effects of the implementations on the current system

1.5 Scope

The time allocation of this research is 420 hours, to finalize the research within this time constraints, there are limitations to this research.

First of all, it is important to be aware that NS does not clean the trains themselves. NS hires a cleaning company for this to be done, HRS. This project, moving cleaning activities from night to daytime, is beneficial for both HRS and NS. It is important to be aware that there is a difference in interests. HRS desires a higher percentage of dayworkers due to the night work restrictions, while NS desires a higher cleaning capacity. This research is performed in the favor of NS. Therefore, the focus of this research will be on gaining cleaning capacity.

This research is about changing the times in this process where the cleaning activities are performed. No investigation will be done on creating a more efficient cleaning process. Therefore, mapping the cleaning process itself does not have a high priority. It is important to know how trains are cleaned to have some insights in the process, but this part of the process will not be changed. Therefore, mapping the cleaning process itself will only be done succinctly.

This research will only focus on two potential solutions. These solutions will be discussed in chapter 4.

In consultation with the client, it is decided to only perform the research for the days Monday till Friday and to exclude the weekends.

Furthermore, this research is an exploratory research on the possibilities and the effects of cleaning trains in daytime. Therefore, the focus will be on the possibilities and the effects. The Cost aspect will not be considered.

2 Literature review

Most of the research is about obtaining relevant information from the timetable of the NS. At the start of the research, the decision was made to create a decision support tool. The goal of the tool is to enable the NS to perform the same analysis again on new versions of data, or with new insides. The literature research will be about a method to perform such a research and what program to use to create a decision support tool.

The scientific method

The scientific method is a method that can be used for research in which data sets are analyzed. This method can be subdivided into four parts: planning, recording, analyzing and reporting.

To start with, the planning stage. This stage is about planning what the research will be about and what tasks have to be performed to get there. A systematic approach always involves planning ahead (Sengupta, 2004). Background research has to be done, a hypothesis needs to be formulated and a method to gather data needs to be thought of. Also, it is important to know by forehand what data needs to be distracted from the data source. This prevents problems in a later stage of the research. This step of the scientific method can be found in chapter 1 and chapter 3.

Second, the recording stage. This stage is about gathering the data and format the data in a way that it is suitable for the analysis. By forehand, it was known which dataset would be used to subtract the data from for the solution support tool. So, this part of the stage was skipped. Nevertheless, the other part of this stage, about data formatting was necessary. The format of this data was not suitable for the data analysis yet. Because of this, an excel file to format the data is created. This file prepares the data for the analysis.

The analysis stage, this is the stage where the statistics and data handling methods are applied. Since the analysis needs to be automated, this stage is very important for this research. To automate the analysis the “solution support tool” is created. A lot of programming in excel VBA was necessary. In this tool every analysis can be performed by simply touching a button.

The reporting stage is about reporting your findings. Basically, this includes describing and visualizing the outcomes of the analysis. For this research a part of this is already directly done in the solution support tool. Further findings are described in the chapters 3 till 5.

The tool

Excel can be used as decision support system. “Because it is ubiquitous, Excel can be used by all managers and business students for exploratory data analysis.” (Markhamb, 2010).

There are various programs that can be used for data analysis. A few examples of commonly used data analysis programs are Python, Matlab and SPSS.

For this research it would be possible to use any of these programs. Unfortunately, during this research an analysis tool will be created for the company which causes constraints. It is very important that every coworker that wants to use this tool is able to use it. “Excel and VBA are flexible tools and you can usually make changes almost at any stage without a great deal of difficulty.” (Sengupta, 2004). Within the NS excel is a commonly used program and everybody know how to use this program (Goorden, 2019). Therefore, the decision is made to use excel as data analysis program and to create the decision support tool in.

The possibilities of Excel programmer are endless (Kofler, 2000). The programming language of excel is VBA, with VBA a lot of functions in excel can be automated (Jacobson, 2001). Therefore, Excel VBA is particularly suitable in this research.

3 The current situation

This chapter answer the first sub question: “How does the current situation look like?” The first part of this chapter, chapter 3.1, describes the cleaning process. Chapter 3.2 describes the performance of the current process. The last part, chapter 3.3, is about the verification of the problem.

3.1 Description of the cleaning process

After a train arrives at its end station, it travels to the marshalling yard and will be offered to HRS to be cleaned. The marshalling yard is controlled by a team that is responsible for all the logistics around incoming and outgoing trains. As you can imagine, this job can be a quite complex puzzle. Especially if there are a lot of trains coming in with only limited spaces to park them. This puzzle gets even more complex if you consider that every train needs to be cleaned and this can only be done at certain cleaning tracks. During the peak hours the activities for the controlling team can get very stressful.

The cleaning process consists of three main elements, the controlling team, the cleaning team and a team leader. The controlling team also keeps an overview on which trains to clean. The controlling team communicates with the cleaning teams through their team leaders. They tell the team leaders which train they have to clean. The cleaning teams work with Maximo, this is an app in which tasks are assigned to the staff and in which the administration is done. Because of Maximo, the staff knows what to clean and it keeps track of the cleaned trains. Also, communication between the team leader and the controlling team is done through Maximo.

The team leader has some extra responsibilities. He or she inspects the train after it is cleaned, manages the team, communicates with the controlling team, takes care of the administration and gives tips to the team about their way of working. The cleaning teams work with a result-oriented cleaning system, “watch, think, do”. For every train there is a list of elements that need to fulfill the quality requirements of NS. Result oriented cleaning means, personnel do only clean the elements that are dirty. The cleaning personnel observes and decides if it is necessary to clean a certain element.

NS is doing research on the most efficient way to clean trains. The ideal systematic way to clean trains is very dependent of the cleaning location. For example, in Zwolle the NS did an experiment to find the optimal systematic to clean the trains. For this location the most optimal cleaning systematic was a cleaning team of six persons. Four persons clean the train, every staff member gets two tasks assigned. The other two staff members consists of the team leader, cooperating, and someone to clean the toilet(s) and fill the water tank(s). The team leader is flexible and performs the cleaning activities where his support is needed

3.2 Performance of the current process

In chapter 1.2, the performance KPI's of NS are introduced. In this paragraph the values of these KPI's will be shown and discussed.

To monitor the performance KPI's NS uses the tool "PowerBi". The data about the performance KPI's in this chapter is deducted from PowerBi.

Table 1 shows the values of the following KPI's, for a period of 10 weeks from week 17 to week 27.

- *NS KPI 1: Percentage of trains that are completely cleaned.*
- *NS KPI 2: Percentage of dirty starters.*
- *NS KPI 3: The amount of trains that are offered for the cleaning process. (per day)*
- *NS KPI 4: Percentage of the cleaning elements of category 1 that meet the quality restrictions.*
- *NS KPI 5: Percentage of the cleaning elements of category 2 that meet the quality restrictions.*

Table 1: Values of the KPI's

	NS KPI 1	NS KPI 2	NS KPI 3	NS KPI 4	NS KPI 5
Week 17	74.51%	4.74%	500.00	97.82%	90.08%
Week 18	75.32%	4.28%	527.71	98.06%	90.26%
Week 19	76.20%	4.51%	507.14	98.31%	91.24%
Week 20	78.30%	4.53%	523.86	97.90%	91.20%
Week 21	77.44%	4.69%	514.43	97.98%	91.03%
Week 22	77.70%	5.13%	413.29	98.28%	90.86%
Week 23	74.49%	4.73%	516.14	98.09%	89.62%
Week 24	74.55%	5.29%	498.57	98.07%	88.81%
Week 25	79.43%	5.33%	508.14	98.29%	92.84%
Week 26	75.86%	6.51%	506.14	98.14%	90.34%
Week 27	78.68%	4.30%	519.57	98.07%	92.25%

As the table indicates (NS KPI 1), only 74% to 80% of the trains can be completely cleaned. Which means that 1 out of 5 trains do not satisfy the standards of the NS. NS KPI 2 shows that about 5% of the trains are not even offered for cleaning and are dirty starters. So, 1 out of 20 trains start their day as they were left the night before. NS KPI 3 shows the total amount of trains that were offered to HRS to be cleaned. This number is quite constant around 500 trains, except for the outlier in week 22. NS KPI 4 and 5 show the percentage of cleaning elements of the specific category that meet the quality requirements. For NS KPI 4 this is around 98% and for NS KPI 5 this is about 90%.

The NS also keeps track of the amount of trains that are labeled as dirty starter. Figure 2 shows the realized number of dirty starters, the target number of dirty starters and the target number at the end of the year. The figure contains data from week 17, 2019 till week 27, 2019.

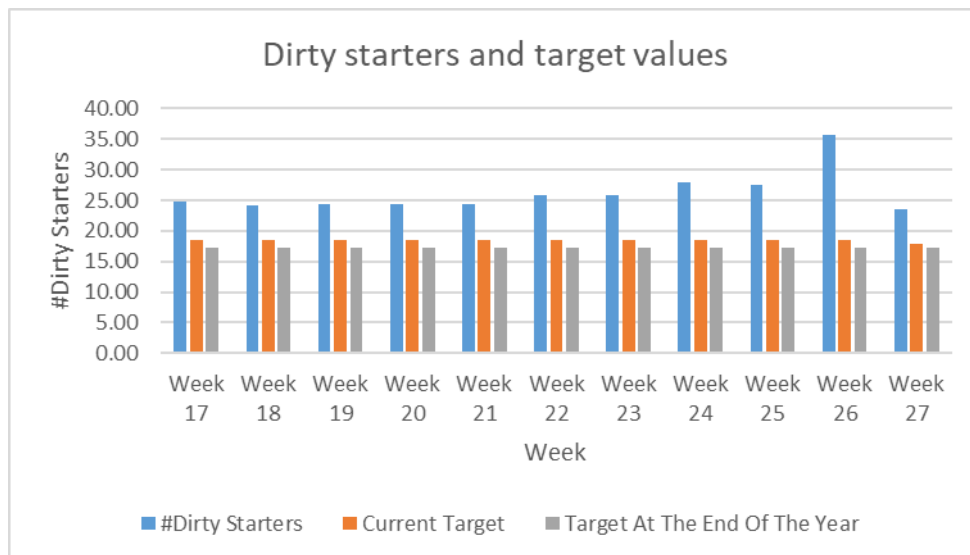


Figure 2: Dirty starters

As figure 2 shows, the targets are not achieved, not once during this ten-week period. This table shows that the system is currently underperforming according to the norms of NS.

It can be concluded that the current system is underperforming and should be improved.

- 1 out of 5 trains are not entirely cleaned.
- 1 out of 20 trains are not cleaned.
- The target number of dirty starters per week, is not even accomplished once in this ten-week period.

So, this leaves opportunities for the improvement of current system.

3.3 Verification of the problem

At the start of the research the client as well as HRS provided a lot of information. This paragraph is about verification of the problem. The two subjects to verify are the spread in the workload and the uncertainty in the end stations of trains.

3.3.1 Spread in the workload

The following data is deducted from the Timetable of NS. The total amount of trains in the system is 669. Section 1.1 mentions that there are over 3.000 train sets. To prevent any confusion, note that a train can consist of multiple train sets.

Not every train is riding every day, some trains are reserve, in use for cleaning and maintenance activities, or just not in use. Because of this not every train needs to be cleaned every night. Only the trains that need to be cleaned are considered. Because of this, there is a difference in the total amount of trains for each day of the week.

Table 2 gives an overview of the distribution of the train arrivals at their end stations for each day of the week. Figure 3 displays the same data in another format.

Table 2: Spread of the arrival times of trains at their end stations

	Monday	Tuesday	Wednesday	Thursday	Friday
<21:00	163	157	157	150	139
21:00-22:00	43	42	49	39	28
22:00-23:00	35	35	35	31	35
23:00-00:00	63	60	62	74	55
00:00-1:00	154	151	147	153	132
1:00-2:00	112	113	106	112	124
2:00-3:00	6	10	12	13	28
3:00-4:00	4	8	7	3	12
Total	580	576	575	575	553

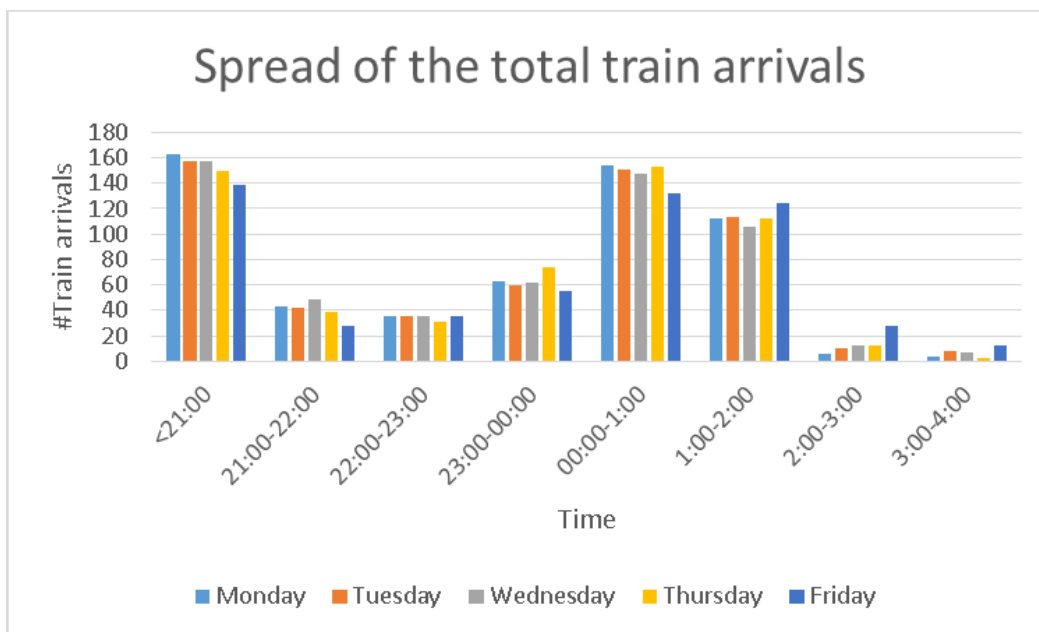


Figure 3: Spread of train arrivals

The amount of trains to clean per night varies between 553 and 580 trains. From the table and the graph, the spread of the arrival of workload can be deducted. They show the arrival of the workload in the given time blocks. Since the cleaning shifts start around 22:00 and sometimes a bit earlier, the first time block starts at 21:00. After 4:00 it is assumed that no trains arrive at their end stations anymore, therefore the last time block is from 3:00 to 4:00.

The cleaning activities start around 22:00. The spread of the workload shows that there are actually two peaks in trains arrivals, all trains that arrive before 21:00 and between 00:00 and 2:00. At the start of the working shift of the cleaning personnel there already are a lot of trains available to clean. The second peak shows the problematic peak that causes the workload to exceed the cleaning capacity. After verification with HRS, the assumption is made that only the trains with an end time between 00:00 and 4:00 cause the problematics. Therefore, this group of trains is called the target group. Additionally, during an experiment at Zwolle the coworkers of NS also acknowledged this sketch of the distribution in the arrival of the workload.

In the first meetings with HRS, they told that almost none of the trains with a cleaning possibility by day are part of the target group. To verify assumption, the distribution of the end times of the trains with a cleaning possibility by day is investigated. Figure 4 shows the distribution of the arrivals of trains with a cleaning possibility by day.

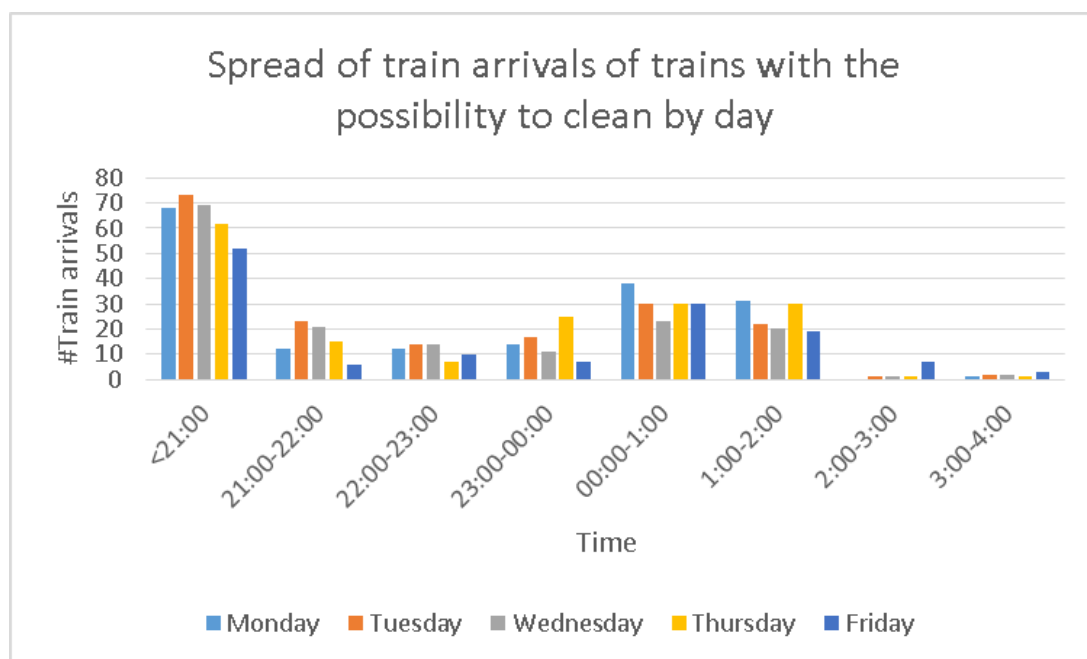


Figure 4: Spread of train arrivals 2

Figure 4 shows that indeed most of the trains that can be cleaned by day are not part of the target group. Nevertheless, there still is a small peak between 00:00 and 2:00. This shows some potential. Most of the trains indeed are not part of the target group, but it is possible to tackle the target group with the current cleaning possibilities in daytime. Therefore, in chapter 4.2, this research will go further in dept on the potency and the effects of using these possibilities to clean trains.

3.3.2 Uncertainty of the end stations of trains

For this research the timetable of NS is used to seek possibilities to solve the capacity issue and to measure their effects. The timetable is a theoretical planning and it is very useful to know how reliable this planning is.

One of the most important pieces of information to deduct from the timetable is the end stations of the trains. The reliability of the end station of a train is used to measure the reliability of the timetable with. This is done because the changes of the timetable by day also affect the end station of a train.

Based on the difference between the realized data and the planned data of the end stations of trains, the certainty is of the end station of a train is measured. Figure 5 shows the certainty of the end station of a train in percentages for every hour of the day. As time passes by it gets more and more certain where a specific train will end. Which is logical, because at the end of the day a train will end, the closer you get to this point the more certain the end station. To clarify the content of the figure an example, between 8:00 and 9:00 the figure shows it is approximately 48% certain that train x will end at the planned end station. Between 15:00 and 16:00 this is approximately 63%.

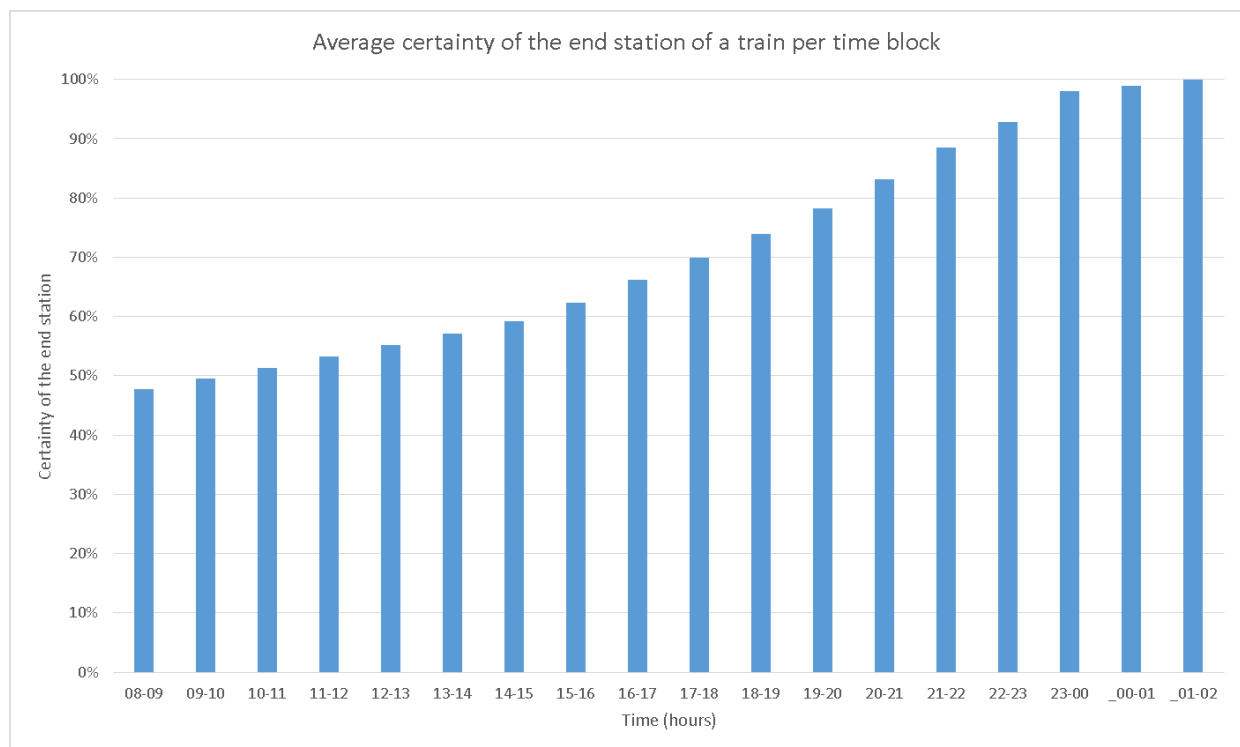


Figure 5: The uncertainty of the end stations of trains against time

Figure 5 clearly shows that there is a huge uncertainty in the end station of a train. The activities regarding the daily cleaning would be between approximately 9:00 and 17:00. Because of this, the end stations of these trains are only between approximately 48% and 65% certain. So, the end stations of the trains are very uncertain. This also indicates that there is a huge uncertainty in the timetable. Because of this it is very complicated to know at what stations the benefits from the cleaning the trains by day will be gained. Also, because of the changes and uncertainty in the timetable, it is not certain that each train will be available for cleaning by day as they would be according to the timetable. For example, if train X would normally be available at station Y between 10:00 and 15:00 to clean and did get another path before 10:00, the cleaning possibility can disappear.

Nevertheless, the uncertainty in the timetable does not indicate that analysis of this information set is useless. Important information can be deducted. Since this research is more of an exploratory research towards the possibilities of cleaning in daytime, the uncertainty will not be a bottleneck. Despite, it is important to know the limitations of the research.

4 Possible solutions

This chapter answers the second sub question: “What are the possibilities and what is their potency on improving the capacity by night?”. The first part, chapter 4.1, is about the possible solutions that this research will cover. Chapter 4.2 will show the potency of the possible solutions. This will be done by experiments and theoretical studies.

4.1 The possible solutions

The first solution is using the current daily excess for cleaning in daytime. Currently, not every train is running the whole day and some trains stand still during the day. Some of these trains are even standing still long enough to clean them. When a train stands still during the day because it is not scheduled for ride, it is called daily excess. The first solution is about using the current daily excess for the cleaning process. This solution is very easy to implement and makes use of the already existing possibilities to clean trains by day. The only aspect that needs to be changed to implement this solution, is the times in which cleaning activities are performed. For the client it is very useful to know the possibilities in the current system, at the start of the research the client already indicated that this information was desired.

The second solution required a bit more time and creativity. This solution is actually an extension of the first solution. The problem is complex and so are the solutions. “How can the current daily excess be expanded in a way that more trains can be cleaned by day, without influencing the timetable?”. After brainstorming and several meetings, a potential idea came up. After consultation with the client, the decision was made to investigate this specific solution. This idea expands the use of the daily excess. Solution two will be explained based on figure 6.

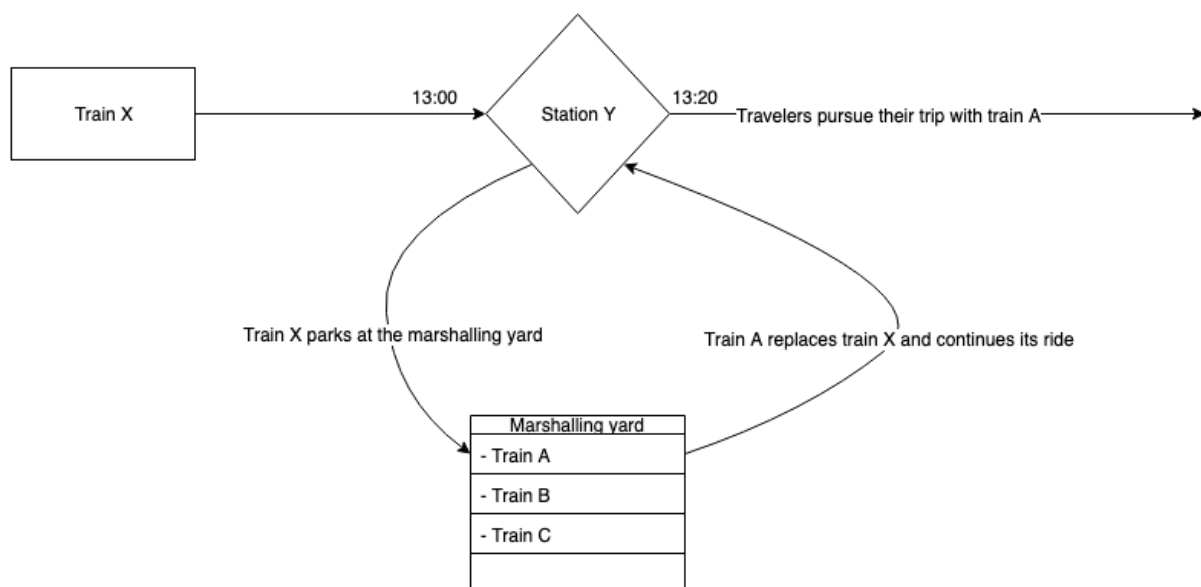


Figure 6: Shifting trains

The concept of this solution is to change trains from the marshalling yard with trains in the timetable to create more cleaning possibilities. Have a look at the example in figure 6. Train X is performing its ride and arrives at 13:00 at station Y. Train X will not pursue its route any further as it would do in the current situation, instead train X will travel to the marshalling yard. Meanwhile, train A travels to station Y and pursues the route of train X at 13:20. Because of this shift, train X also spends time at the marshalling yard where the train can be cleaned. This is called shifting trains.

In the current situation only train A would have an opportunity to be cleaned in daytime. The shifting trains solution creates an additional opportunity for train X.

So, by changing a train from the marshalling yard with a train that is running, the cleaning possibilities by day can be extended. Of course, there are several constraints to this solution. Shifting trains is not possible in every situation, this will be elaborated in chapter 4.2.2.

4.2 Potency of the solutions

The potency of a solution is defined by the amount of times, the possibility occurs to clean a train in daytime and the benefits it causes during the peak hours by night. To investigate the daily excess and the shifting trains solution, the solution support tool is used.

Methodology

To investigate the timetable, the decision support tool is used. The input values of the variables are set in consultation with the NS. The following variables were used as the input for the excel model. The bold printed letters are the values of the input variables.

- The time range of performing the cleaning activities is set between **9:00** and **17:00**.
- The minimal standing still time is set to **80 minutes**. Because traveling to a marshalling yard is assumed to be 20 minutes, this directly assumes that at least $(80 - 2 \cdot 20 =)$ 40 minutes are needed to clean a train.

Also, some assumptions were made:

- It is assumed that only the trains with an arrival time between 00:00 and 4:00, cause the problematic peak in the workload. This group is called the target group.
- Every train that is cleaned by day does not need to be cleaned by night.

For further research into the solutions, several experiments are done. The main goals of the experiments are to verify if shifting trains and cleaning by day is feasible. This will be tested with two different experiments.

4.2.1 Using the daily excess to clean trains

To show the potency of this solution several KPI's and variables are used. These KPI's and variables will be described below, their values will be given for Monday to Friday:

- *Variable 1: The total amount of trains that have to be cleaned.*
This variable displays the volume of the cleaning activities.
- *KPI 1: The amount of trains that can be cleaned by day.*
This KPI creates insights in the volume of the cleaning possibilities by day while using the daily excess.
- *Variable 2: The amount of trains that arrive at their end station after 00:00.*
This variable shows the volume of the target group.
- *KPI 2: The amount of trains that can be cleaned by day and arrive at their end station after 00:00.*
This KPI displays the amount of trains from the target group that are available for cleaning in daytime.

- *KPI 3: The percentage of trains that can be cleaned in daytime by the use of daily excess.*
This KPI gives an indication of the potential impact of using daily excess on the cleaning system.
- *KPI 4: The percentage of trains of the target group that can be cleaned in daytime by the use of daily excess.*
This KPI gives an indication on what part of the target group can be handled during cleaning in daytime.

Table 3 displays the values of KPI's 1 to 4 and variables 1 and 2.

Table 3: The outcome of the KPI's 1 to 4 and variable 1 and 2, for every day of the week.

	Monday	Tuesday	Wednesday	Thursday	Friday
<i>Variable 1</i>	580	576	575	575	553
<i>KPI 1</i>	174	176	159	170	130
<i>Variable 2</i>	276	282	272	281	296
<i>KPI 2</i>	70	55	46	62	59
<i>KPI 3</i>	30.00%	30.56%	27.65%	29.57%	23.51%
<i>KPI 4</i>	25.36%	19.5%	16.91%	22.06%	19.93%

For a low volume of trains to clean on a station, it will be too expensive to schedule personnel. KPI 1 and 2 shows that the number of trains that can be cleaned in day time is has quite some volume. This is very positive.

KPI 3 shows that between 23% and 31% of the total amount of trains that have to be cleaned, have an opportunity to be cleaned in day time. This percentage indicates that using the daily excess has a lot of potency. It is important to keep in mind that not every cleaning possibility is realistic. For example, if there is only one train to clean at a certain station, which only takes an hour, then it will probably be too costly to schedule cleaning personnel.

KPI 4 shows that between 17% and 25% of the target group can be cleaned in day time. These percentages are very promising and show that the problem group can be tackled by cleaning in day time.

4.2.2 *Shifting trains*

The potency of this solution is shown by highlighting the following two aspects:

- The maximal impact: How much trains of the target group can be cleaned, on top, with shifting trains? This data is gathered by using the solution support tool.
- The feasibility: is it even possible to shift trains? This is done by two experiments.

The goal of table 4 is to show how much the shifting trains solution can extend the cleaning possibilities in daytime. The amount of trains of the target group that can be cleaned by using daily excess is shown. Next to that, the amount of extra trains of the target group can be cleaned because of the extension of shifting trains. The last column shows this growth in percentages. To clarify the content let's take Monday as an example. On Monday 70 trains of the target group can be cleaned in daytime, the solution of shifting trains can increase this number with 21. So, for Monday, the shifting trains solution extends the amount of trains of the target group that can be cleaned in daytime by 30%. Figure 7 shows the amount of trains that can be cleaned by using the current daily excess and the added value of shifting trains.

Table 4: Potency of shifting trains

	#Trains daily excess	#Trains added by shifting trains	Improvement %
Monday	70	21	30.00%
Tuesday	55	19	34.55%
Wednesday	46	16	34.78%
Thursday	62	20	32.26%
Friday	59	18	30.51%

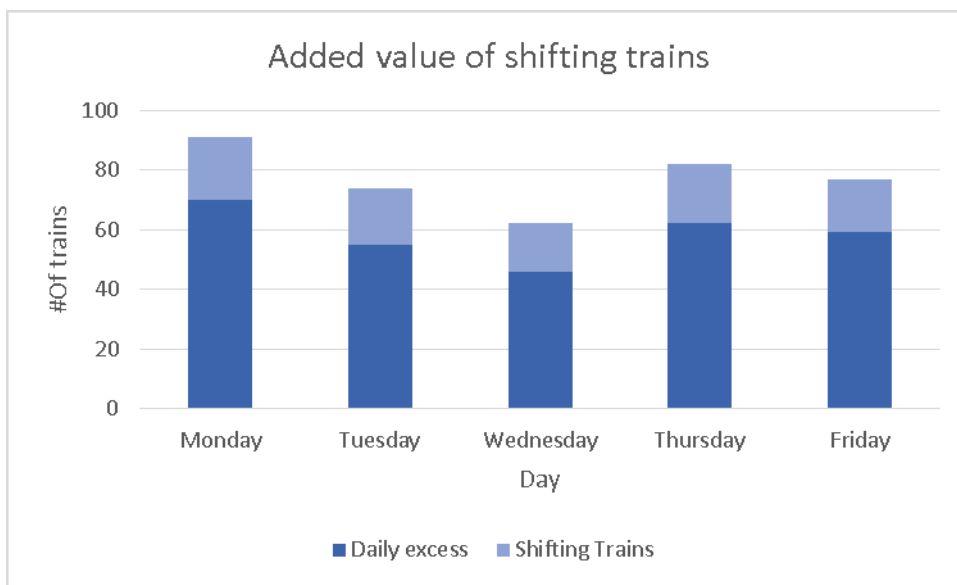


Figure 7: Potency of shifting trains, visualized

Table 4 as well as figure 7 indicate that solution of shifting trains improves the situations quite significantly. The trains of the target group that can be cleaned in daytime can be extended with at least 30%, for every day.

The theoretical study showed promising results. Therefore, experiments are performed to check the feasibility of this solution. The experiments were both performed at Zwolle. The first experiment was to perform one single change between two trains to see if this was possible. The experiment succeeded and the shift was performed accordingly. This experiment proves that the solution of shifting trains is feasible.

The second experiment is almost similar, but the goal was to perform 3 changes of two trains. With this experiment, a cleaning team was scheduled at Zwolle to clean trains. This experiment was also to test if cleaning in daytime is possible and if any difficulties are encountered. During the experiment three trains were cleaned. Because of this, it was possible to measure the pollution of the train during the day. This is interesting to know since it shows how dirty a train gets if it is only cleaned in daytime. If trains get really dirty after the cleaning in daytime, the NS might decide that these trains need an additional short cleaning routine by night. With this measure it possible to see if it is realistic to say that trains that are cleaned in daytime do not have to be cleaned by night.

This second experiment had some difficulties. Due to last minute changes in the timetable only 1 of the trains that would be changed with trains from the marshalling yard, arrived at Zwolle. Because of this only one train could be changed with a train from the marshalling yard. It was a pity, but this confirms the uncertainty in the timetable as discussed in chapter 3.3.2. Nevertheless, three trains were cleaned and no problems were encountered with performing the cleaning activities.

The NS attaches great value to the customer satisfaction. It is important to know how dirty a train would start the following day if it is only cleaned in daytime, because this affects the customer satisfaction. Therefore, the degradation of the cleanliness level of the train is also considered in this experiment. To get knowledge about this degradation and the status in which a train would start with its shift the next day, measures were performed on one train. One of the inspectors of NS performed a quality measure during the night. With this measure information was acquired about the pollution of the train during the day. In appendix D some pictures of the status of this train by night can be found. The remark of the inspector was, cleaning in daytime certainly was of added value. Still, the inspector gave the advice to perform a short cleaning routine on these trains. For example, only emptying trashcans. The advice from the inspector does not necessarily indicate that only performing cleaning activities in daytime does not satisfy, this only is a recommendation from the inspector personally. The NS might think that a short cleaning routine by night is unnecessary for these trains.

5 Implementation

In chapter 4.2 the potency of the two solutions is shown. This chapter answers the third sub question: “How to use the possible solutions optimally to lower the workload during the peak hours?”. The first part, chapter 5.1, will be about the implementation strategy. The second part, chapter 5.2, will show the impact from the implementation strategies on the current system.

5.1 Implementation strategy

This chapter discusses the implementation strategy of the two solutions.

General strategy

The implementation strategy for both solutions is almost the same. Shifting trains only has an additional strategy for shifting the trains. Cleaning in daytime is beneficial if trains from the target group are available to clean. Cleaning this group of trains in daytime causes the peak in the workload that exceeds the cleaning capacity to drop. So, the first choice in the implementation strategy is to only clean trains from the target group in daytime.

Second, not every cleaning location has a high enough workload to schedule staff by day. Because of this not every station can be used as a cleaning station. In consultation with HRS the following requirements for scheduling staff at a cleaning station are established:

- The minimum amount of staff members scheduled for a cleaning shift is two persons. Due to this restriction, only stations with a workload during the shift of at least 13.6 men hours can be used as cleaning stations.
- The length of a cleaning shift should cover 8 hours. Sporadically a shift could be a bit shorter or longer, but this should not be the standard.

Since the strategy is to only clean the target group, stations with enough workload from this specific target group will be used as cleaning stations. So, for the implementation all the stations that satisfy these constraints will be used to clean trains.

To summarize, every station that has a workload of at least 13.6 men hours of the target group is used as cleaning station. All the trains of the target group will be cleaned at the cleaning stations. Further on in this chapter the potential cleaning stations will be listed.

For the explanation of the strategy of the shifts figure 8 is used.

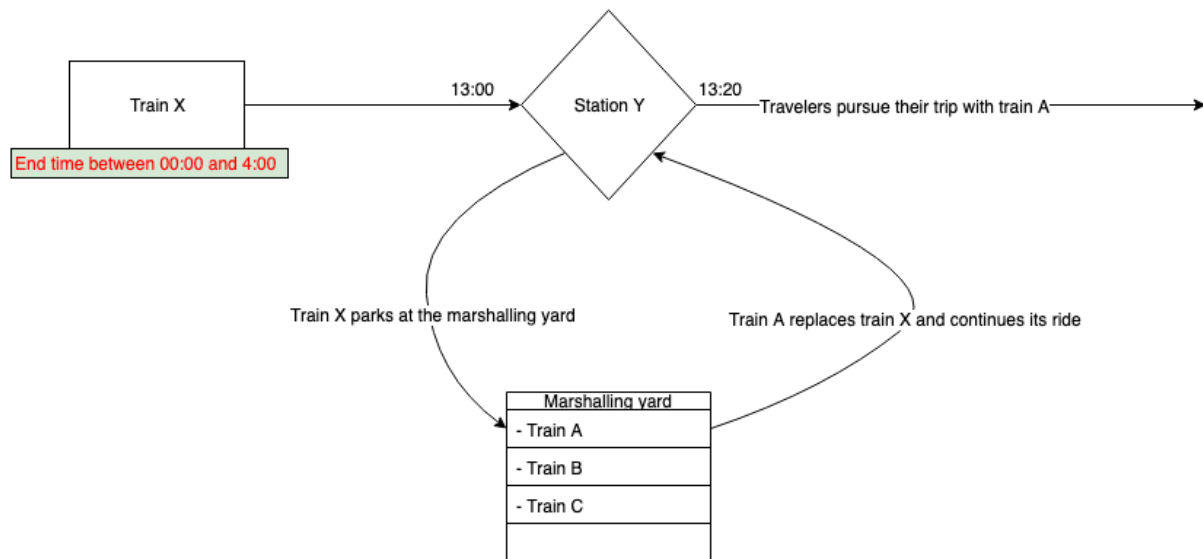


Figure 8: Shifting trains strategy

This figure is almost the same as figure 7. The difference from the figure 7 is the green box, in the left upper corner, below train X. Since train A takes over the route of Train X, train A will also take over the end station and the end time of train X. So, the end time of train A is not important for deciding which shift to execute. Train X takes over the end time of train A, so train X does not necessarily need to be cleaned. Train X would then only be cleaned if the original end time of train A is between 00:00 and 4:00. This is because the new end time of train X would then also be between 00:00 and 4:00. Since train A takes over the end station and end time of train X, train A always needs to be cleaned.

So, the strategy for the shifting trains solution is to only change trains, that are available for a change with another train and have an end time between 00:00 and 4:00. For example, train X in figure 8.

For performing the shifts and calculating the possibilities the solution support tool is used. Chapter 6 describes how this tool works and which assumptions are made.

Recommendations

There are also a few downsides. The end stations of the trains are hugely spread and the end station of a train is very uncertain. Because of this it is very difficult to conclude where and how much benefit will be gained at the end stations. Due to this uncertainty, it is not yet possible to schedule less personnel by night. If the volume of trains that are cleaned by day is increased, this might be feasible in the future. For the current situation this is not possible. This means that cleaning in daytime for the current situation will not result in a financial benefit. Nevertheless, it increases the cleaning capacity and it will result in better values for the NS KPI's, discussed in chapter 1.2. So, future research on the prediction of the end stations of trains would expand the benefits of cleaning by day. If the end station can be predicted, it is possible to know by forehand at which stations which benefits will be gained.

The use of the daily excess could be extended by using mobile cleaning units or multidisciplinary staff.

- *Multidisciplinary staff*

A common problem is that the workload for the graffiti cleaning is very uncertain. Because of this, a lot of times the staff is not able to perform working activities during their shift. In these lost hours the graffiti staff could be used to clean trains. So, making these graffiti cleaners multidisciplinary would reduce their lost hours and they can be used to clean trains.

- *Mobile cleaning units*

Workload is spread over a lot of stations. For some stations the workload is too small to schedule a cleaning team. Creating mobile cleaning units would solve this problem and makes it possible to clean more trains in daytime.

These two options are spoken of with HRS, both are feasible. For now, the use of mobile units is out of range. This due to the costs and the lack of experience in the cleaning during daytime. The use of the multidisciplinary teams seems to have the most potential, since this would be very easy to implement. HRS told that it is possible, but it needs some implementation time. This is because, graffiti cleaners are proud on their job. Their job is not the internal cleaning of a train but cleaning the graffiti of trains. So, this change needs some time settle with the cleaners and the organization.

5.2 The effects/benefits

Table 5 shows the cleaning stations that came out of the solution support tool for every day of the week. The locations that are not bold marked, are the potential cleaning locations if the current daily excess is used to clean trains. The bold marked locations are the cleaning locations that are added for the implementation of shifting trains.

Table 5: Cleaning stations

Monday	Tuesday	Wednesday	Thursday	Friday
Bkh	VI	Rtd	Rtd	Amr
Rtd	Rtd		Bkh	Hfdo
Amr	Amr		Hfdo	Rtd
ZI	ZI		Amr	
			Rsd	

Figure 9 shows the percentage of trains of the target group that can be cleaned by day for each solution. This figure shows the impact that the implementations will have on the peak in the workload by night.

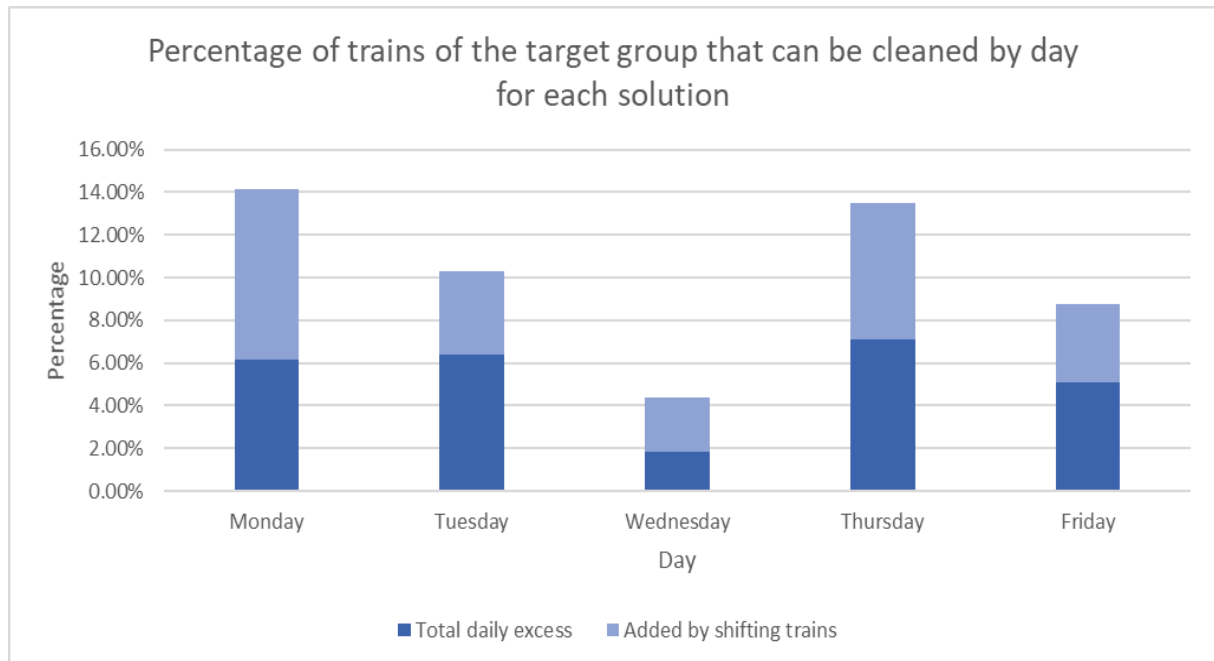


Figure 9: The impact at night

The figure shows that the implementations have quite some impact. Apart from Wednesday approximately 10% of the trains of the target group can be cleaned by day, if both solutions are implemented. Also, figure 9 shows that the shifting trains solution almost doubles the amount of trains of the target group that can be cleaned in daytime. This is because shifting trains enables a lot of potential cleaning locations.

In appendix E an overview can be found of the end stations of the trains that are cleaned by day for each day of the week for each solution. This tables can be used to see at which stations the benefits are gained from the cleaning activities by day. Because the end stations are very uncertain this research does not go in depth on station specific benefits. Because the trains have a huge spread in the end stations of the cleaned trains, most probably the daily cleaning activities will not cause that less personnel can be scheduled by night. This might be possible in the future if the daily cleaning will be extended even more. Nevertheless, the advantages of these cleaning activities can be gained with an improvement of the KPI's of NS. More trains can be cleaned every day and the cleaning capacity is increased.

6 Decision support tool

This chapter is about the developed tool in excel. A lot of analyses in this research are done based on this tool. This chapter will describe how the tool works, how various values are calculated and what assumptions are made.

Visual Basics (VBA) is a programming language inside excel and can be used to automate and extend current functions of excel. With the use of excel VBA, the decision support tool is created. A lot of functions and comparisons to analyze data are automated. The goal of the tool is to enable the NS to perform the same data analysis with other input data and variables very fast and efficiently. This is very useful if the NS gets new insides or data. The NS can directly adapt the input variables to their preferences or change the input data.

To start with, some general assumptions of the solution support tool:

- Several claims are used on trains. A claim is a comment on train. For example, a claim can indicate a maintenance activity. The tool looks at claims as if it are rides. So, if a train is scheduled two hours for a maintenance activity, the tool looks at it as if this is a ride. Therefore, the possibility of cleaning a train while a claim is scheduled is not possible.
- Every station contains one cleaning location.
- The cleaning location of the end station of the train is the location where the train is cleaned.

6.1 Input data and data structure

For every ten-week period, the NS creates a new timetable. The timetable is the input data for the decision support tool. Before the data can be used the data needs to be adapted. To prepare the data and to make sure the data format is correct, the excel file “Data formatter” is created. The input of this file are two data sets. A dataset containing the timetable and a dataset containing the night transitions. In the timetable unique trains are not labeled, only the route and type of train are shown. The dataset of the night transitions shows to which route a train will change by night. For example, if train X starts at route 1 on day 1, this can change to route 3 on day 2. These changes can be found in the data set of the night transitions. Combining those two data sets makes it possible to track specific trains in the timetable. The routes of a train are displayed by the group that the train is part of and the number of the route. Routes are always performed by a specific type of train. For example, if there is a certain group “BBA” and there are 3 routes performed by this group, these routes would be indicated by BBA1, BBA2 and BBA3. These routes can only be driven by trains of group “BBA”. In the solution support tool, unique trains are indicated with their route indication on day 1 of week 1 of the timetable.

The file “Data formatter” consists of four sheets:

- Timetable
The timetable to analyze has to be copied into this sheet.
- WeekNumber
The timetable contains information for 10 weeks. In this sheet the week to analyze can be chosen.
- NightTransitions
The information about the night transitions, of the timetable to analyze, has to be copied into this sheet.
- NightTrainstionsAdjusted
This sheet presents same data as the sheet “NightTransitions”, but with another format. This way the data can be used more easily.

The file that contains the data of the night transitions is called “Materieelovergangen” and the file that contains the data of the timetable is called “Materieelactiviteiten”. These two data files are coming from the NS, for every 10 week period they publish new files. Figure 10 shows how to transport the data from “Materieelovergangen” (the file at the left of figure 10) into “Data formatter” (the file at the right of figure 10). Note that the data has to be copied to the sheet “NightTransitions” of the file “Data formatter”.

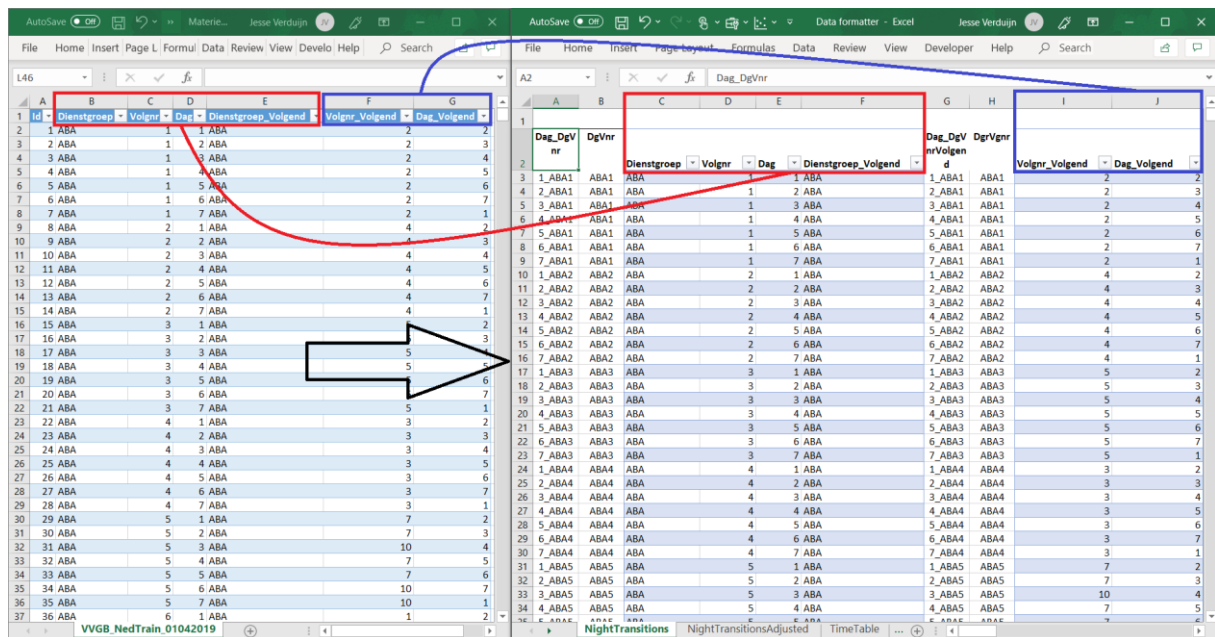


Figure 10: Night Transitions

The data of columns B, C, D and E (Figure 10 in the left, red square) is copied to columns C, D, E and F (Figure 10 in the right, red square). For columns F and G (Figure 10 in the left, blue square) the data is copied to columns I and J (Figure 10 in the right, blue square). Be aware that the first row of columns C, D, E, F, I and J of “data formatter” is and should stay empty. For transporting the data from “Materieelactiviteiten” to “Data formatter”, the data of columns A till N is copied into the same columns in the sheet “timetable” of the file “Data formatter”.

The data of the other columns will automatically adapt to the new input data. Two sheets of “Data formatter” that are not shown yet. The “WeekNumber” sheet and the “NightTransitionsAdjusted” sheet. The sheet “NightTransitionsAdjusted” represents the data of the sheet “NightTransitions” so that it can be used in “Timetable” for the unique trains. The sheet “Weeknumber” is to choose the week number of the timetable that is shown in “Timetable”. The timetable is exactly the same for every week, but due to the night transitions the corresponding routes are not driven by the same trains. For this research the week number is not relevant, but if the user wants to track a certain train for multiple weeks, this is possible.

Right now, the data is ready to transport to the solution support tool. The data from the sheet “timetable” of “Data formatter” is the input for the solution support tool and should be copied and pasted to sheet “VVGB_NedTrain_09062019”. Once this is done, the data should be sorted in a different way. First, DayNum (column D) should be sorted from low to high. Second, DrgVlgnrDag1Wk1 (column Q) should be sorted from A to Z. The order of performing the sorting tasks is important, first sort DayNum and second sort DrgVlgnrDag1Wk1. To sort the data, click at the right side of the header of the column (Figure 11, red circle). Once this button is pushed the first option should be chosen (Figure 11, green square).

Id	Dienst	Volnr	Dag	Dagtijdsrelatie	Vertrek	Aankomst	Treinserie	Trnr	Positie	Drglpunt_vertrek	Drglpunt_aankomst	Claim	Verschiltijden	DrgpVlgnr	Week
1															
2					0	545	838	9200	9211 -	Brusz	Asd			4 ABA1	
3					0	842	850	79200	79211 -	Asd	Wgm			141 ABA1	
4					0	1111	1119	79200	79232 -	Wgm	Asd			6 ABA1	
5					0	1125	1417	9200	9232 -	Asd	Brusz			28 ABA1	
6					0	1445	1720	9200	9247 -	Brusz	Gv			79 ABA1	
7					0	1839	2117	9200	9260 -	Gv	Brusz			0 ABA1	
8					0	644	920	9200	9215 -	Brusz	Gv			79 ABA2	
9					0	1039	1317	9200	9228 -	Gv	Brusz			28 ABA2	
10					0	1345	1638	9200	9243 -	Brusz	Asd			5 ABA2	
11					0	1643	1651	79200	79243 -	Asd	Wgm			140 ABA2	
12					0	1911	1919	79200	79264 -	Wgm	Asd			6 ABA2	
13					0	1925	2217	9200	9264 -	Asd	Brusz			0 ABA2	
14					0	845	1138	9200	9223 -	Brusz	Asd			5 ABA4	
15					0	1143	1151	79200	79223 -	Asd	Wgm			80 ABA4	
16					0	1311	1319	79200	79240 -	Wgm	Asd			6 ABA4	
17					0	1325	1617	9200	9240 -	Asd	Brusz			28 ABA4	
18					0	1645	1938	9200	9255 -	Brusz	Asd			47 ABA4	
19					0	2025	2317	9200	9268 -	Asd	Brusz			0 ABA4	
20					0	744	1038	9200	9219 -	Brusz	Asd			5 ABA3	
21	107 ABA		3	4	0	1043	1051	79200	79219 -	Asd	Wgm			80 ABA3	
22	108 ABA		3	4	0	1211	1219	79200	79236 -	Wgm	Asd			6 ABA3	
23	109 ABA		3	4	0	1225	1517	9200	9236 -	Asd	Brusz			27 ABA3	
24	110 ABA		3	4	0	1544	1838	9200	9251 -	Brusz	Asd			5 ABA3	
25	111 ABA		3	4	0	1843	1851	79200	79251 -	Asd	Wgm			331 ABA3	
26	112 ABA		3	4	1	22	30	79200	79212 -	Wgm	Asd			0 ABA3	
27	205 ABA		5	5	0	555	917	9200	9212 -	Asd	Brusz			28 ABA5	
28	206 ABA		5	5	0	945	1238	9200	9227 -	Brusz	Asd			5 ABA5	
29	207 ABA		5	5	0	1243	1251	79200	79227 -	Asd	Wgm			140 ABA5	
30	208 ABA		5	5	0	1511	1519	79200	79248 -	Wgm	Asd			6 ABA5	
31	209 ABA		5	5	0	1525	1817	9200	9248 -	Asd	Brusz			28 ABA5	

Figure 11: VVGB_NedTrain_09062019

Now the data is ready for the solution support tool to perform the analysis on.

Decision support tool

As is also visible in figure 11, the excel file of the decision support tool consists of ten sheets. For every sheet, a description about its functionality and the data presented is given. The description will be given on the basis of a screenshot of the sheet.

VVGB_NedTrain_09062019

Figure 11 also directly displays the first sheet. This is the input data of the solution support tool and this data is used to perform the analyses. Every row displays a ride of a train. Since the content of this table is only used as input data and not for the user to extract data from, the content of the columns will not be described.

AmountOfTrains

Figure 12 displays a screenshot of this sheet. If the button, Calc amount of trains, is pushed, the sheet creates a list of all the trains in the system and calculates the total amount of trains. The list of trains is represented in column A, blue square. The amount of trains is shown at the right of this column, indicated by the yellow circle in figure 12.

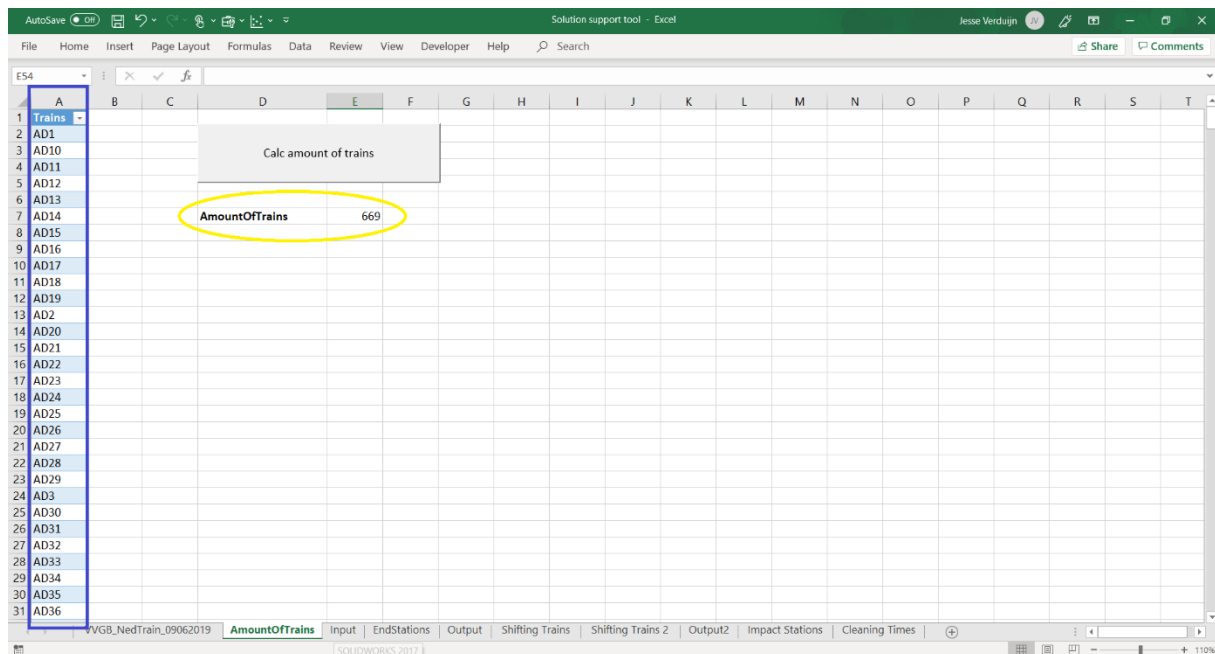


Figure 12: AmountOfTrains

Input

In this sheet the user can choose several input variables for the data analysis.

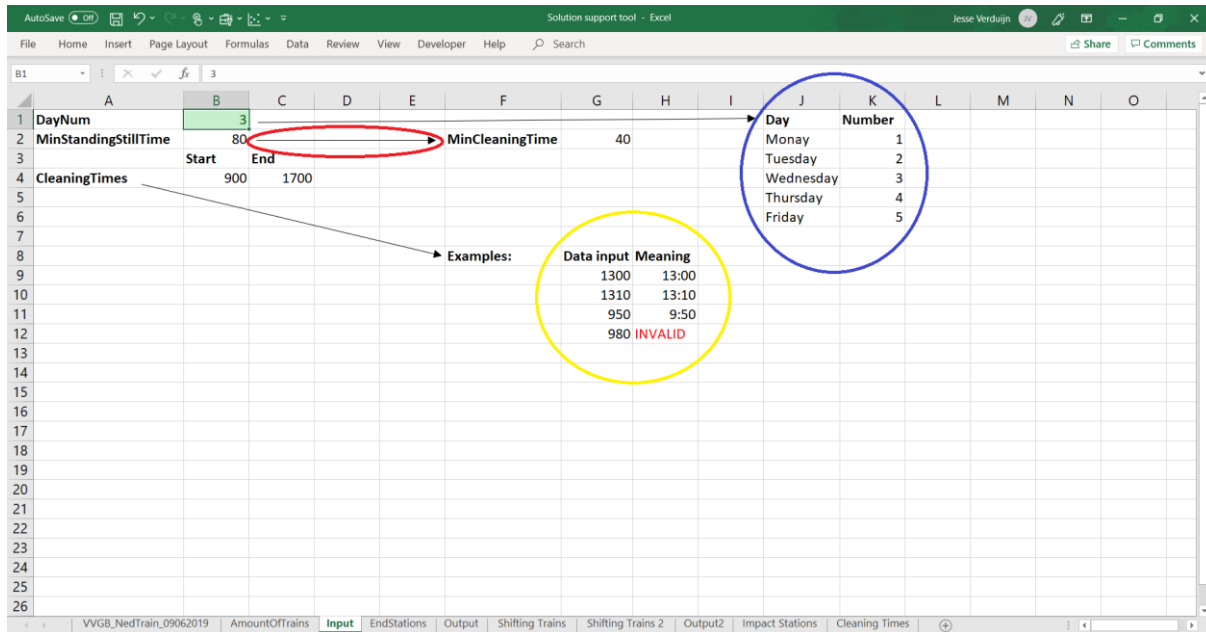


Figure 13: Input

As figure 13 indicates, there are four input variables for the user to choose: DayNum, MinStandingStillTime and CleaningTimes Start & End. The variable DayNum is to choose the day to analyze. Every day has his own number and the index is shown in columns J and K (Figure 13, blue circle). With the variable MinStandingStillTime the user can tell how long a train minimally needs to stand still to be able to clean it, in minutes. As the arrow (Figure 13, red circle) indicates the MinCleaningTime (minimal cleaning time) is dependent on this variable. In this research it is assumed that it takes 20 minutes to go from a station to a cleaning location and the other way around. So, the remaining time to clean a train is then the standing still time minus 40 minutes. Therefore, the MinCleaningTime is MinStandingStillTime minus 40 minutes. With the variables CleaningTimes Start & End, the user can indicate between which times the cleaning activities will take place. The format of the input data for this variable is integer. The time expression is the same as used in the army, for example 13:00 is 1300. In the sheet there are some more examples (Figure 13, yellow circle).

EndStations

The function of this sheet is to analyze the end stations and end times of the trains for the chosen day in the sheet “input”. To calculate the end times of the trains it is assumed that all trains arrive at their end station before 4:00.

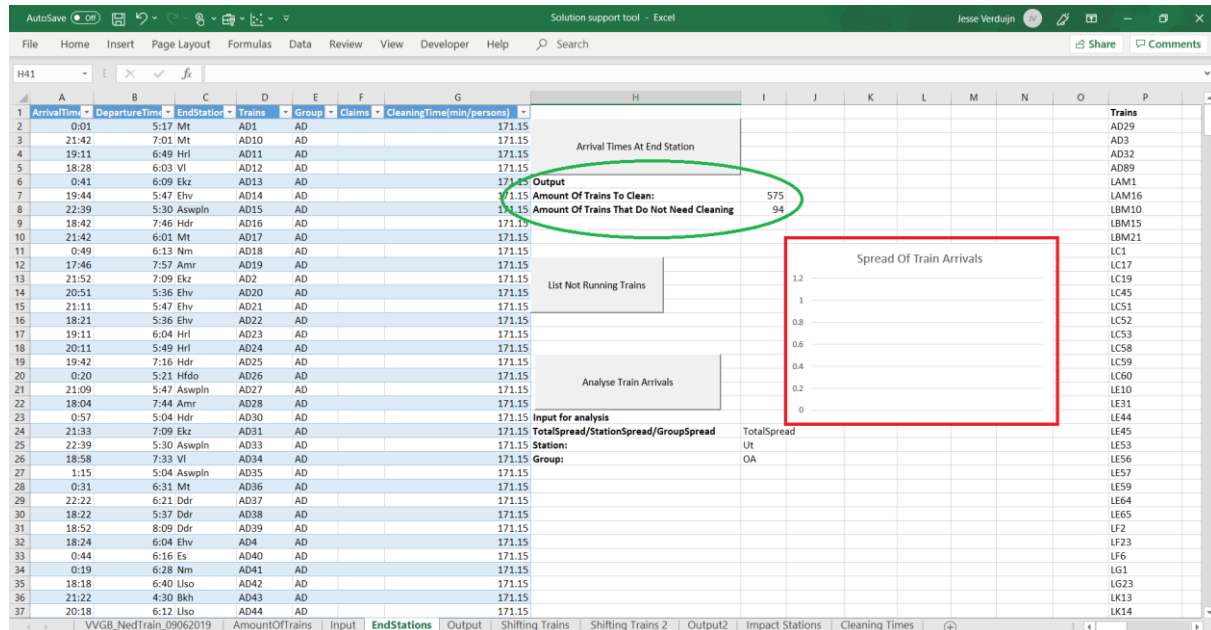


Figure 14: EndStations, List Not Running Trains

This sheet contains three buttons, see figure 14:

- Arrival Times At End Station

If this button is pushed, the data in the table at the left of the button (column A till G) is refreshed. For every train the end time for the selected day is found. This is done using the data of sheet “VVGB_NedTrain_09062019”. The output variables below the button (Figure 14, green circle) will also be refreshed. The output variables show the total amount of trains that need to be cleaned and the amount of trains that do not have to be cleaned for the selected day. Trains that do not need to be cleaned, are trains that do not transport people that day or trains that are only scheduled for maintenance the following day.

The data shown in the columns of the table, from left to right, is:

- ArrivalTime, the arrival time of the train at its end station.
- DepartureTime, the departure time of the train for the first run of the following day.
- EndStation, the end station of the train.
- Trains, the specific train that the row with information is about.
- Group, the train group that the train is part of.
- Claims, a claim is a special comment for the specific ride. If the first run after the train arrives at the end station contains a claim, the claim is displayed in this column. The input data contains a small percentage of inconsistencies. Because of this it is possible that the tool calculates two end times and end stations for one train. If this happens the value in this column is “error”.
- CleaningTime, this column displays the cleaning time in minutes that are needed to clean the train with one staff member.

- *List Not Running trains.*

Figure 14 displays the layout of the sheet if this button is pushed. The function of this button is to list all the trains that do not need to be cleaned. The list of trains will be displayed in column P. Furthermore, the figure in this sheet (Figure 14, red square) is not displaying any useful information if the button is pushed.

- *Analyze Train Arrivals.*

If this button is pushed the sheet gets another layout. To explain the function of this button figure 15 will be used. The function is to analyze the distribution of the train arrivals. For every time block, the amount of trains with an end time in this time interval will be calculated. This information will be displayed in a table as well as in a figure. The input for this function is the table at the left of this button (column A till G). The information about the end times is deducted from column A.

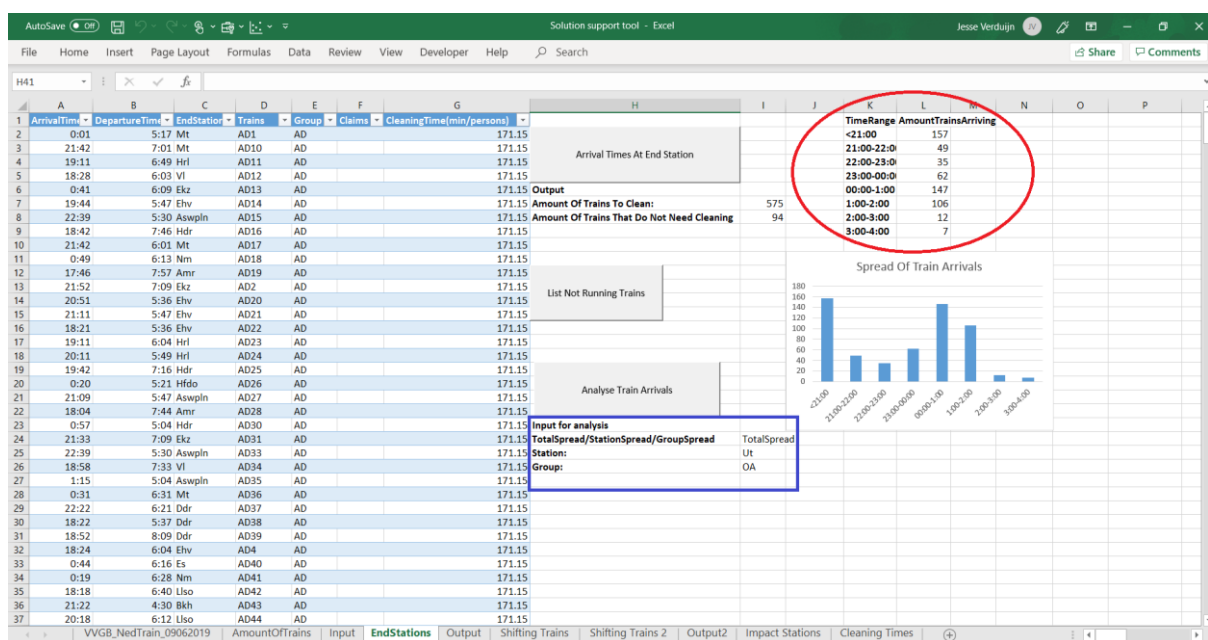


Figure 15: EndStations, Analyze Train Arrivals

If this button is pushed the table (Figure 15, red circle) will be created or refreshed. The figure below the table displays the content of the table visually. Below the button (Figure 15, blue square) the user can choose several input variables for the analysis. As figure 15 indicates, column P is cleared after pushing this button. This also goes the other way around, if “List Not Running Trains” is pushed, column K and L are cleared. For the first input variable, the user can choose TotalSpread, StationSpread or GroupSpread.

- If TotalSpread is chosen, the distribution of the workload of all the trains in the table at the left side of the button will be shown. The variables “Station:” and “Group:” will not be used if this option is chosen.
- If StationSpread is chosen, the variable “Station:” should also be filled with the station to analyze. The information about the end stations is deducted from column C. The distribution of the end times of all the trains with the chosen end station will be shown. For example, if Utrecht (Ut) is chosen, the data display shows the spread of the arrivals at Utrecht station.

- If GroupSpread is chosen, the variable “Group” should also be filled with the group to analyze. The information about the group of the trains is deducted from column E. The distribution in of the end times of all the trains that are part of the chosen group will be shown. For example, if the group “OA” is chosen, the data display shows the spread of the arrivals of this group of trains.

Output

Figure 16 shows the layout of this sheet. The function of this sheet is to show the possibilities and the potential of using the daily excess with the chosen input variables in the sheet “Input”.

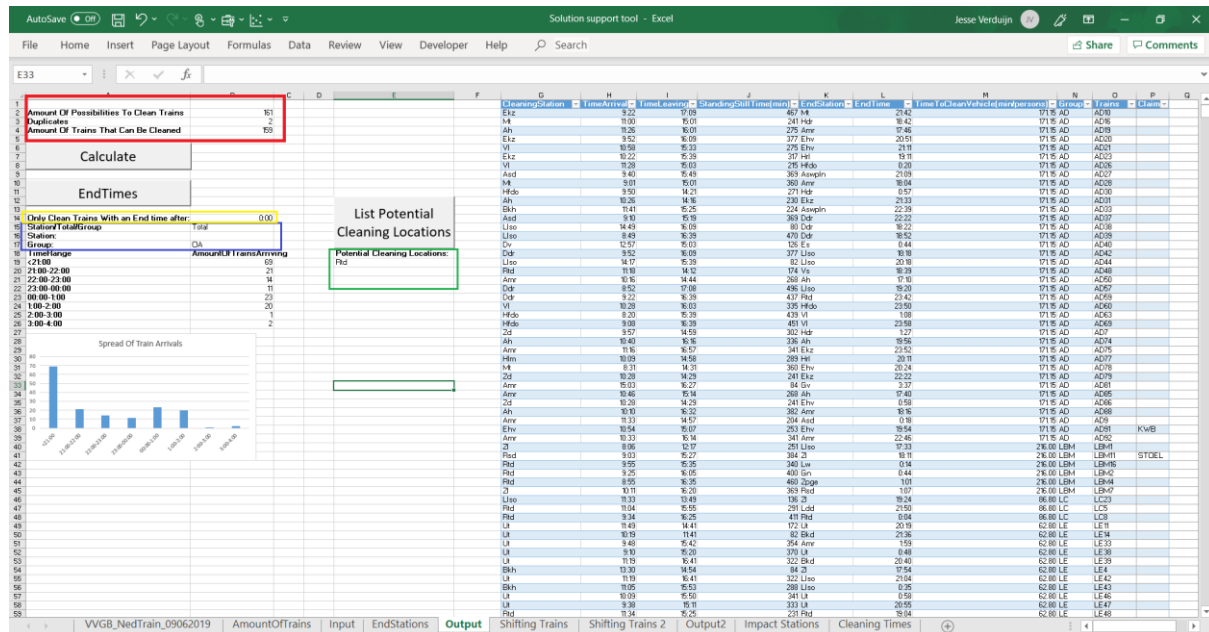


Figure 16: Output

The sheet contains three buttons:

- Calculate

This function calculates three output variables for the possibilities of using the daily excess: the amount of possibilities to clean trains, the duplicates and the amount of trains that can be cleaned. These output variables can be found above the button (Figure 16, red square). A train is labelled as duplicate if there are two possibilities for one train to be cleaned. So, the amount of possibilities to clean trains minus the duplicates is the amount of trains that can be cleaned. This function refreshes the content of the table at the right side of the sheet (columns G till P). Every row in the table is a possibility to clean a train. Every row consists of 10 columns of information. For every column, from left to right, a short description of the content of the data will be given below.

- CleaningStation, the station where the train can be cleaned by day.
- TimeArrival, the time that the train arrives at the station where it can be cleaned. Be aware that it is assumed that it takes 20 minutes to get from the station to the cleaning location.
- TimeLeaving, the time that the train leaves the station where it can be cleaned. Be aware that it is assumed that it takes 20 minutes to get from the cleaning location to the station.
- StandingStillTime, the time between the arrival and the departure of the train.

- EndStation, the end station of the train. This information is coming from the table in the sheet “EndStations”.
 - EndTime, the end time of the train. This information is coming from the table in the sheet “EndStations”.
 - TimeToCleanVehicle, this column displays the cleaning time in minutes that are needed to clean the train with one staff member.
 - Group, the train group that the train is part of.
 - Trains, the specific train that the row of information is about
 - Claim, this information is coming from the table in the sheet “EndStations”
- *EndTimes*
- The input for this function is the table at the right side of the sheet (column G till P). Below the button (Figure 16, blue square) there are several options to choose for the analysis. This basically is the same function as the button “Analyze Train Arrivals” in the sheet “EndStations”. The only difference is the input data and the three options are now called Station, Total and Group instead of StationSpread, TotalSpread and GroupSpread. Also, the input for the group is now coming from column N, for the end times from column L and for the end station column K. Just like the function “Analyze Train Arrivals”, the output is displayed in a table as well as in a figure. The table and the figure are displayed below the input variables.
- *List Potential Cleaning Locations*
- For this function one input variable can be chosen (Figure 16, yellow square), “Only clean trains with an end time after:”. This input variable allows the user to target a certain group of trains. For example, if 22:00 is chosen, only trains with an end time between 22:00 and 4:00 are cleaned. The latest time is 4:00 because it is assumed that every train ends before 4:00 at its end station. This function will for every station, count the workload of the trains that can be cleaned by day of this target group. If the workload is 13.7 hours or more, the station will be listed below the button (Figure 16, green square). The reason for the minimum of 13.7 hours is a constraint from HRS.

Now that the potential cleaning location(s) are known the table can be used to show all cleaning possibilities for these stations. To do so click on the right side of the column header of “CleaningStation” (Figure 17, red circle) and then select the potential cleaning stations (Figure 17, blue square).

CleaningStation	TimeArrival	TimeLeaving	StandingStillTime(min)	EndStation	EndTime	TimeToCleanVehicle(min/persons)	Group	Trains	Claim
1	10:03	15:27	324 Wgm	171.15 AD	0:20			AD10	
2	10:41	15:49	308 Ehw	171.15 AD	0:58			AD14	
3	10:22	15:39	317 Ekz	171.15 AD	23:52			AD17	
4	15:00	17:07	127 Nm	171.15 AD	22:47			AD18	
5	8:54	16:07	433 Hdr	171.15 AD	18:42			AD2	
6	9:22	17:09	467 Hrl	171.15 AD	20:41			AD20	
7	9:52	14:39	287 Ehw	171.15 AD	19:51			AD21	
8	11:24	15:07	223 Mt	171.15 AD	21:00			AD22	
9	11:54	16:07	253 Hdr	171.15 AD	18:42			AD31	
10	9:57	14:59	302 Ah	171.15 AD	22:56			AD36	
11	9:21	17:13	472 Hgl	171.15 AD	0:32			AD38	
12	9:40	17:49	369 Bkh	171.15 AD	22:52			AD39	
13	10:07	14:55	288 Bkh	171.15 AD	19:43			AD40	
14	11:41	15:25	224 Bkh	171.15 AD	20:07			AD41	
15	9:10	15:19	369 Ddr	171.15 AD	22:22			AD42	
16	11:18	14:12	174 Vs	171.15 AD	18:39			AD43	
17	10:18	14:42	264 Rsd	171.15 AD	18:00			AD44	
18	8:49	15:40	411 Lso	171.15 AD	20:17			AD49	
19	9:22	16:09	407 Lso	171.15 AD	18:18			AD53	
20	9:52	16:39	407 Bkd	171.15 AD	23:57			AD54	
21	10:20	16:39	379 Ddr	171.15 AD	18:52			AD55	
22	9:48	16:09	381 Rsd	171.15 AD	19:37			AD57	
23	8:52	17:08	496 Ddr	171.15 AD	21:22			AD58	
24	9:58	15:03	305 Vi	171.15 AD	19:58			AD60	
25	11:28	16:03	275 Hfdo	171.15 AD	23:50			AD65	
26	8:50	16:09	439 Vi	171.15 AD	23:28			AD66	
27	10:58	15:03	245 Hfdo	171.15 AD	0:20			AD68	
28	8:20	16:39	499 Vi	171.15 AD	23:58			AD69	
29	11:26	15:46	260 Nm	171.15 AD	0:49			AD73	
30	12:11	17:14	303 Ut	171.15 AD	0:08			AD74	
31	8:08	11:21	193 Ut	171.15 AD	0:18			AD75	
32	10:40	16:01	321 Zd	171.15 AD	21:20			AD77	
33	10:10	16:16	366 Nm	171.15 AD	1:50			AD78	

Figure 17: Output, cleaning location

Shifting Trains

In this sheet the chosen day number from the sheet “Input” is not considered. This is because the functions of this sheet directly perform the calculations for the whole week.

ArrivalTime	DepartureTime	CleaningStation	Group	Train	Day	StandingStillTime	MinTimeToShift	Trains
1	1023	1507 Amr	AD	AD10	1	324	20	AD10
2	820	1352 Rsd	AD	AD10	5	372		AD10
3	953	1437 Amr	AD	AD11	2	324		AD10
4	1042	1519 Ekz	AD	AD11	4	317		AD10
5	1042	1449 Ehw	AD	AD13	5	287		AD10
6	1101	1529 Hrl	AD	AD14	1	308		AD10
7	1120	1441 Mt	AD	AD16	3	241		AD10
8	1042	1519 Ekz	AD	AD17	1	317		AD10
9	1014	1417 Ehw	AD	AD17	5	281		AD10
10	1200	1412 Ah	AD	AD18	4	172		AD10
11	1017	1439 Zd	AD	AD19	2	302		AD10
12	1146	1541 Ah	AD	AD19	3	275		AD10
13	1120	1547 Ehw	AD	AD19	4	151		AD10
14	914	1547 Ehw	AD	AD2	1	433		AD10
15	1012	1549 Ekz	AD	AD20	3	377		AD10
16	1012	1419 Ekz	AD	AD21	1	287		AD10
17	1018	1513 Vi	AD	AD21	3	275		AD10
18	1018	1543 Vi	AD	AD21	4	365		AD10
19	1006	1524 Amr	AD	AD21	5	358		AD10
20	1146	1547 Ehw	AD	AD22	1	222		AD10
21	1201	1433 Bkh	AD	AD22	5	192		AD10
22	1012	1549 Ekz	AD	AD23	2	377		AD10
23	1042	1519 Ekz	AD	AD23	3	317		AD10
24	1012	1519 Ekz	AD	AD23	5	347		AD10
25	936	1624 Amr	AD	AD25	5	448		AD10
26	1148	1443 Vi	AD	AD26	3	215		AD10
27	1201	1433 Bkh	AD	AD27	2	192		AD10
28	1000	1529 Amr	AD	AD27	3	369		AD10
29	1131	1529 Hrl	AD	AD27	4	278		AD10
30	1023	1437 Amr	AD	AD27	5	294		AD10
31	1101	1529 Hrl	AD	AD28	2	308		AD10
32	921	1441 Mt	AD	AD28	3	360		AD10
33	1030	1556 Ah	AD	AD28	4	366		AD10
34	1053	1507 Amr	AD	AD3	5	294		AD10
35	1010	1401 Hfdo	AD	AD30	3	271		AD10
36	1244	1547 Ehw	AD	AD31	1	253		AD10
37	1046	1356 Ah	AD	AD31	3	230		AD10
38	1029	1438 Hlm	AD	AD31	5	289		AD10
39	1201	1505 Bkh	AD	AD33	3	224		AD10
40	1008	1519 Liso	AD	AD33	5	351		AD10
41	1017	1439 Zd	AD	AD36	1	302		AD10

Figure 18: Shifting Trains

The table at the left (column A till G) displays all the events where trains from the cleaning location can be changed with trains that arrive at the station. A train from the cleaning location can be changed if the train spends at least two times the “MinCleaningTime”, from the sheet “Input”, at the cleaning location. This table is refreshed by the button “List Potential Trains To Change”.

The function goes through every row of the sheet “VVGB_NedTrain_09062019” to see if there are trains that stand still long enough at the cleaning location to change with another train.

The table at the right in Figure 18 (starting at column M), displays every train that arrives at a station and can be changed with a train at a cleaning station. The content of this table is refreshed by the button “Possible Changes”. The input variable of this function is the MinTimeToShift (Figure 18, red circle). Trains that arrive at a station can be changed with a train at a cleaning location if:

- The train stands still for “MinTimeToShift” minutes.
- There is a train of the same group at the marshalling yard to change with.

With the variable “MinTimeToShift” the user can choose the minimal time a train needs to stand still at a station to change it with a train from the cleaning location. This is because it takes a while to put another train at platform where the travelers can get in. For every row in the table at the left side of the sheet, the function goes through the sheet “VVGB_NedTrain_09062019” to list every possible change. Basically, the table at the left are the trains that stand still at the cleaning locations and the table at the right are the trains that arrive at a station and can be changed with the trains from the cleaning location.

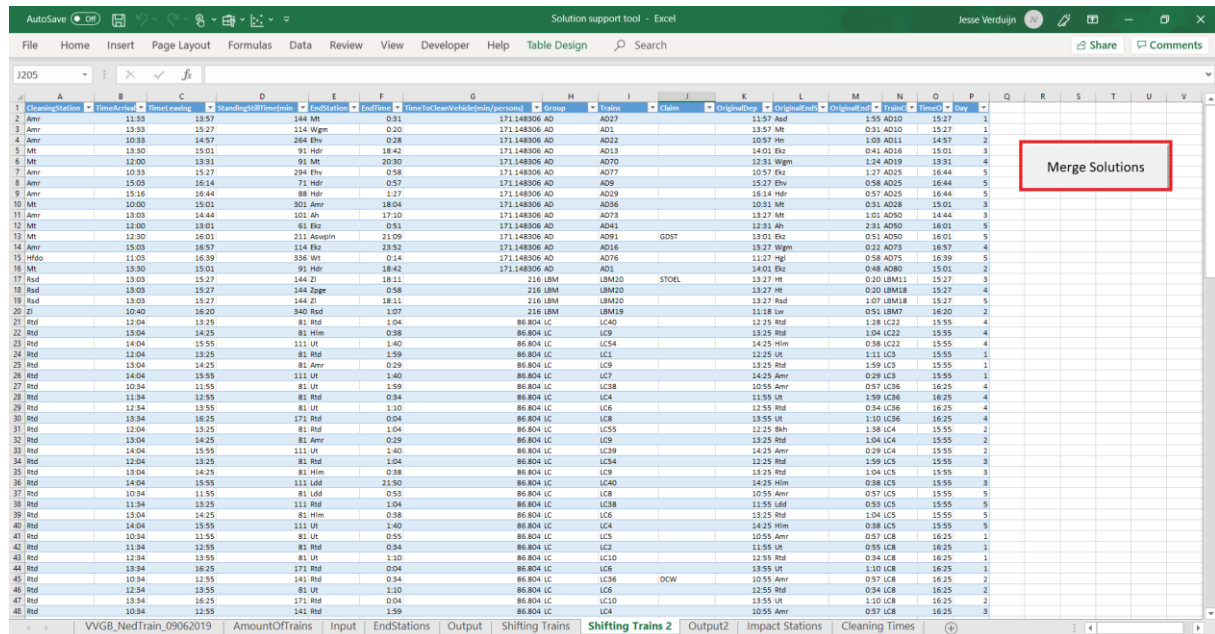
It is not possible to execute every change possibility. The button “Create Schedule” is provided with a heuristic that chooses which possible changes, from the table at the right of the sheet, are executed. For every execution, the train that goes from the station to the cleaning location will be listed in the sheet “Shifting Trains 2”. If a train changes its route with another train, its end station and end time changes. This change is directly processed and visible in the table. For this function there are three input variables that can be chosen (Figure 18, blue circle):

- *Only schedule trains with end time after:*
This way the user can target a specific group of trains. Only trains with an end time after the chosen time, will be considered.
- *Filter trains with daily excess:*
Some of the trains with a possibility to change, also have the possibility to be cleaned during the current daily excess. If the user wants to exclude this trains from the changing possibilities, this is possible. For the input “Yes” these trains will be filtered, for “No” these trains will not be filtered.
- *Specific station:*
If the user wants to see the possible changes for one station only, the abbreviation of the desired station should be used as input variable. With this option the sheet “Shifting trains 2”, will be filled only with possible changes for this specific station. This option is very useful if the user wants to test the shifting train solution at a certain station. If the input cell is left blank, the function will list all possible changes in “Shifting trains 2”.

The heuristic is very simple, the first train that arrives at a certain station, from the same group of the train at the cleaning station, will be used to change with the train at the cleaning location. It is a first come first serve methodic. Every train will perform the maximum of 1 change.

Shifting Trains 2

This sheet contains a big table. Every row is a train that goes to a cleaning location because of a change with another train. The first ten columns of the table contain the same type of data as the first ten columns in the big table of the sheet “output”. The other columns are used to save information about the train where the change is performed with, the original end time and the original end station.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
	CleaningStation	TimeArrival	TimeLeave	StandingInTime	Initiation	EndTime	TimeToCleanVehicleTime	Location	Group	Train	Claim	OriginalEnd	OriginalEndSt	OriginalEndSt	Time	Day						
1	Amr	11:33	13:57	244 Wgn	0:31			171.148306 AD	A027		11:57 Rtd	1:55 AD010	15:27	1								
2	Amr	11:33	15:27	114 Wgn	0:20			171.148306 AD	AD1		11:57 Mtr	0:31 AD010	15:27	1								
3	Amr	10:33	14:57	264 Ehw	0:28			171.148306 AD	AD22		10:57 Mtr	1:03 AD011	14:57	2								
4	Mt	13:30	15:01	91 Mtr	18:42			171.148306 AD	AD13		14:01 Ehw	0:41 AD018	15:01	3								
5	Mt	12:00	13:31	91 Mtr	20:30			171.148306 AD	AD70		12:31 Wgn	1:24 AD019	13:31	4								
6	Amr	10:33	15:27	294 Ehw	0:58			171.148306 AD	AD77		10:57 Ehw	1:17 AD015	16:44	5								
7	Amr	15:03	16:14	71 Mtr	0:57			171.148306 AD	A09		15:27 Ehw	0:58 AD025	16:44	5								
8	Amr	15:16	16:44	88 Mtr	1:27			171.148306 AD	AD29		16:14 Mtr	0:57 AD025	16:44	5								
9	Mt	10:00	15:01	301 Amr	18:04			171.148306 AD	AD36		10:31 Mtr	0:31 AD028	15:01	3								
10	Amr	13:03	14:44	101 Mtr	17:10			171.148306 AD	AD73		13:27 Mtr	1:01 AD020	14:44	3								
11	Mt	12:00	13:01	61 Ehw	0:51			171.148306 AD	AD41		12:31 Mtr	2:31 AD050	16:01	5								
12	Mt	12:30	16:01	211 Amr	21:09			171.148306 AD	AD91	GOST	13:01 Ehw	0:51 AD050	16:01	5								
13	Amr	15:03	16:57	114 Ehw	23:52			171.148306 AD	AD16		15:27 Wgn	0:32 AD072	16:57	4								
14	Mtr	11:03	16:39	336 Wtr	0:14			171.148306 AD	AD76		11:27 Mtr	0:58 AD075	16:39	5								
15	Mtr	13:30	15:01	91 Mtr	18:42			171.148306 AD	AD1		14:01 Ehw	0:48 AD080	15:01	2								
16	Rtd	13:03	15:27	144 Zt	18:11			216 LBM	LB020	STOL	13:27 Mtr	0:20 LB011	15:27	3								
17	Rtd	13:03	15:27	144 Zt	0:58			216 LBM	LB020		13:27 Mtr	0:20 LB018	15:27	4								
18	Rtd	13:03	15:27	144 Zt	18:11			216 LBM	LB018		13:27 Rtd	1:07 LB018	15:27	5								
19	Zt	10:40	16:20	240 Rtd	1:07			216 LBM	LB018		11:18 Wtr	0:51 LB017	16:20	2								
20	Rtd	12:04	13:25	81 Rtd	1:04			86.804 LC	LC40		12:25 Rtd	1:28 LC22	15:55	4								
21	Rtd	13:04	14:25	81 Mtr	0:38			86.804 LC	LC9		13:25 Rtd	1:04 LC22	15:55	4								
22	Rtd	14:04	15:55	111 Wtr	1:40			86.804 LC	LC54		14:25 Mtr	0:38 LC22	15:55	4								
23	Rtd	12:04	13:25	81 Rtd	1:59			86.804 LC	LC1		12:25 Wtr	1:11 LC3	15:55	1								
24	Rtd	13:04	14:25	81 Amr	0:29			86.804 LC	LC9		13:25 Rtd	1:59 LC3	15:55	1								
25	Rtd	14:04	15:55	111 Wtr	1:40			86.804 LC	LC7		14:25 Amr	0:39 LC3	15:55	1								
26	Rtd	10:34	11:55	81 Wtr	1:59			86.804 LC	LC38		10:55 Amr	0:57 LC36	16:25	4								
27	Rtd	11:34	12:55	81 Rtd	0:34			86.804 LC	LC4		11:55 Wtr	1:59 LC36	16:25	4								
28	Rtd	12:34	13:55	81 Wtr	1:10			86.804 LC	LC6		12:55 Rtd	0:34 LC36	16:25	4								
29	Rtd	13:34	14:55	171 Rtd	0:04			86.804 LC	LC8		13:55 Wtr	1:10 LC36	16:25	4								
30	Rtd	12:04	13:25	81 Rtd	1:04			86.804 LC	LC55		12:25 Bth	1:38 LC4	15:55	2								
31	Rtd	13:04	14:25	81 Amr	0:29			86.804 LC	LC9		13:25 Rtd	1:04 LC4	15:55	2								
32	Rtd	14:04	15:55	111 Wtr	1:40			86.804 LC	LC39		14:25 Amr	0:29 LC4	15:55	2								
33	Rtd	12:04	13:25	81 Rtd	1:04			86.804 LC	LC54		12:25 Rtd	1:59 LC5	15:55	3								
34	Rtd	13:04	14:25	81 Mtr	0:38			86.804 LC	LC9		13:25 Rtd	1:04 LC5	15:55	3								
35	Rtd	14:04	15:55	111 Ldd	21:50			86.804 LC	LC40		14:25 Mtr	0:38 LC5	15:55	3								
36	Rtd	10:34	11:55	81 Ldd	0:53			86.804 LC	LC8		10:55 Amr	0:57 LC5	15:55	5								
37	Rtd	11:34	12:55	111 Rtd	1:04			86.804 LC	LC38		11:55 Ldd	0:53 LC5	15:55	5								
38	Rtd	13:04	14:25	81 Mtr	0:38			86.804 LC	LC6		13:25 Rtd	1:04 LC5	15:55	5								
39	Rtd	14:04	15:55	111 Wtr	1:40			86.804 LC	LC4		14:25 Mtr	0:38 LC5	15:55	5								
40	Rtd	10:34	11:55	81 Wtr	0:55			86.804 LC	LC5		10:55 Amr	0:57 LC8	16:25	1								
41	Rtd	11:34	12:55	81 Rtd	0:34			86.804 LC	LC2		11:55 Wtr	0:55 LC8	16:25	1								
42	Rtd	12:34	13:55	81 Wtr	1:10			86.804 LC	LC10		12:55 Rtd	0:34 LC8	16:25	1								
43	Rtd	13:34	14:55	171 Rtd	0:04			86.804 LC	LC6		13:55 Wtr	1:10 LC8	16:25	1								
44	Rtd	10:34	11:55	141 Rtd	0:34			86.804 LC	LC36	DCW	10:55 Amr	0:57 LC8	16:25	2								
45	Rtd	12:34	13:55	81 Wtr	1:10			86.804 LC	LC6		12:55 Rtd	0:34 LC8	16:25	2								
46	Rtd	13:34	14:55	171 Rtd	0:04			86.804 LC	LC10		13:55 Wtr	1:10 LC8	16:25	2								
47	Rtd	10:34	11:55	141 Rtd	1:59			86.804 LC	LC4		10:55 Amr	0:57 LC8	16:25	3								

Figure 19: Shifting Trains 2

The only button in this sheet is “merge solutions” (Figure 19, red square). The function of this button is to merge the table of “Output” with the table in the sheet “shifting trains 2” into one table in “Output 2”. This way the sheet “Output 2” presents the same data as the sheet “Output”, but now with the executed train changes added. This way it is possible to see the effects of cleaning in daytime using the daily excess with the extension of shifting trains.

Output 2

This sheet has almost the same layout as the sheet “output”. The goal of this sheet is to show the added value of shifting trains compared to only using the daily excess. The functions “list potential cleaning locations” are the same. The function “EndTimes” in “Output” is exactly the same as the function “Impact Of Shifting Trains” in “Output 2”. The only difference is that in this sheet all output variables are compared to the output variables in “Output”. In figure 20, the blue squares are the values with the extension of shifting trains and the red squares are the values for only using the daily excess. The table and the figure in column A till C, show the deviation of train arrivals for the shifting train solution and the added value of shifting trains (Figure 20, pink square). The input variables in the sheet “Output” are exactly the same as in this sheet.

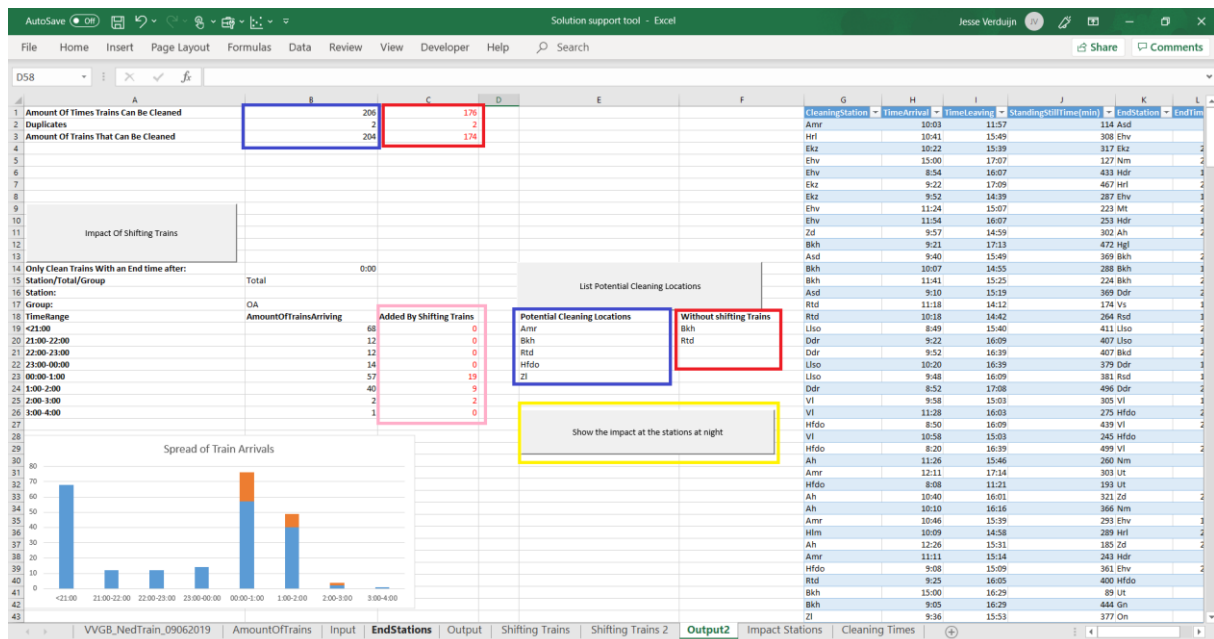


Figure 20: Output 2

This sheet contains one button with another function than in the sheet “output” (Figure 20, yellow square). The function of this button is to show the impact at night if the potential cleaning stations are used. The impact is shown by presenting data in the next sheet impact stations. This calculation is done for the potential cleaning locations of both, the use of daily excess and shifting trains.

Impact Stations

The table in this sheet shows the end stations of the trains that can be cleaned by day and how many of these trains end at these stations. This way the impact of cleaning at the cleaning locations by day on the cleaning locations by night is shown. The results of daily excess and shifting trains are displayed next to each other to be able to see the added value of shifting trains. The same data is also displayed in a figure next to the table. Furthermore, the sheet shows two output variables (Figure 21, red circle): total shifting trains and total daily excess. Both variables show how much trains of the target group, can be cleaned by day using the potential cleaning locations.

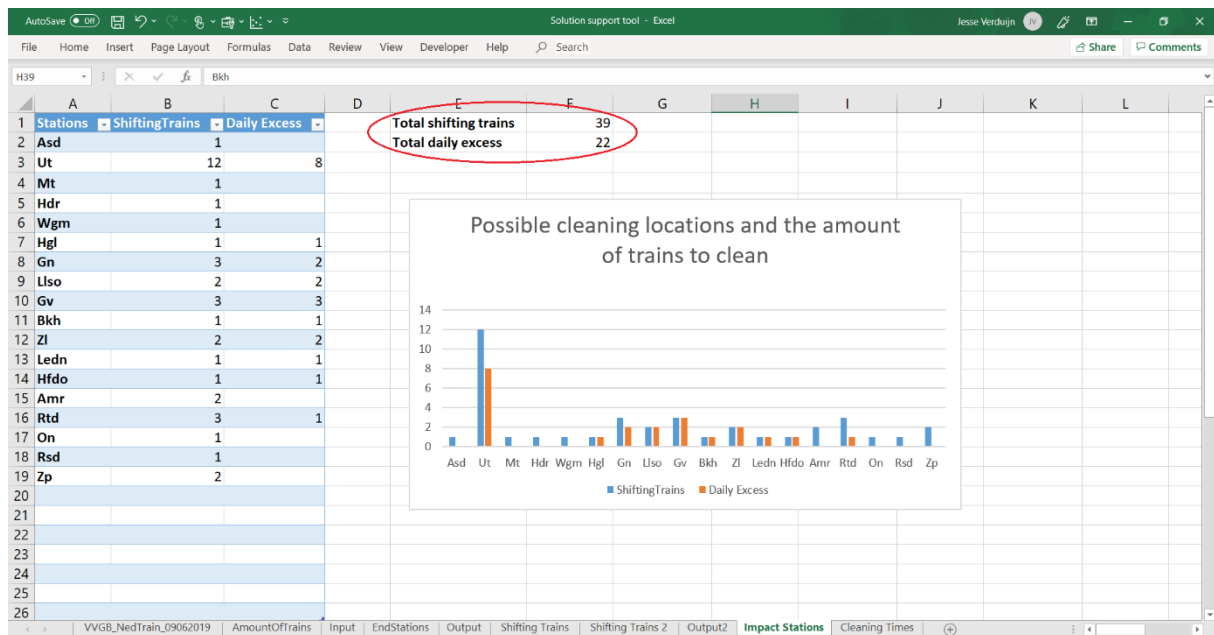


Figure 21: Impact Stations

Cleaning Times

This sheet contains the information about the cleaning times for every group of trains. Only trains that are part of one of the train groups of which this sheet contains information, are considered in the analyses of the tool. Figure 22 displays a screenshot of this sheet.

AutoSave

Excel

Figure 22: Cleaning Times

7 Conclusion, discussion and recommendations

Chapter 7.1 is the conclusion of this research. Chapter 7.2 contains the discussion and recommendations will be given in chapter 7.3.

7.1 Conclusion

In this research two possibilities of shifting cleaning activities from night to daytime are discussed. The use of the current daily excess already showed some promising results. The second solution, shifting trains, is an extension of using the daily excess. In this research the focus really is on the target group of trains, because this group causes the problematics in the workload during the night cleaning. Therefore, targeting this specific group will cause the most benefits by night. The shifting trains solution can increase the number of trains of the target group that can be cleaned in daytime with at least 30% compared to using daily excess. Table 6 shows the percentage of trains of the target group that can be cleaned by day. This is shown for the daily excess, the added value of shifting trains and the total impact.

Table 6: The total theoretical impact on the target group

	Monday	Tuesday	Wednesday	Thursday	Friday
Daily excess	25.36%	19.50%	16.91%	22.06%	19.93%
Added by shifting trains	7.61%	6.74%	5.88%	7.12%	6.08%
Total	32.97%	26.24%	22.79%	29.18%	26.01%

Nevertheless, this is all theoretical. HRS gave some constraints for the cleaning locations. With these constraints taken into account, the percentages were a bit lower, but still showed a lot of potential. Table 7 displays the same information as Table 6, but with the constraints taken into account.

Table 7: The total potential impact on the target group

	Monday	Tuesday	Wednesday	Thursday	Friday
Daily excess	7.97%	3.90%	2.57%	6.41%	3.72%
Added by shifting trains	6.16%	6.38%	1.84%	7.12%	5.07%
Total	14.13%	10.28%	4.41%	13.52%	8.78%

At the start of the research, it is concluded that the peak in the workload by night causes the problematics in the cleaning capacity. For this reason, the target group is chosen as the group of trains that cause this peak. Getting rid of this peak also holds getting rid of the exceeding workload during the peak hours. So, what is the impact of using the potential cleaning locations? Figure 23 shows the average distribution of the workload by night for three situations:

- The current situation
- The situation in which the daily excess is used to clean trains
- The situation in which the daily excess is used with the extension of the shifting trains solution.

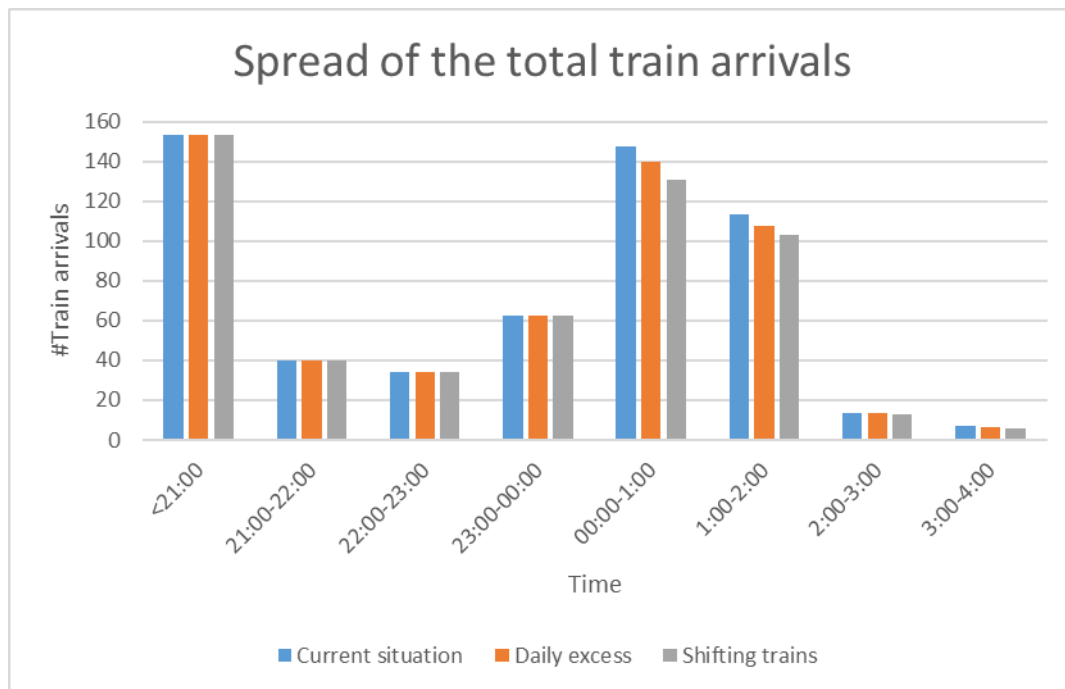


Figure 23: Impact on the peak

As the figure 23 indicates the solutions do help to lower the peak in the workload. This causes an improved capacity and an improved system. Nevertheless, there still is a huge peak in the workload between 00:00 and 2:00. This indicates that even after implementing the two solutions there is room for further improvement.

The results of implementing these solutions will mainly be an improvement on the NS KPI's, discussed in chapter 1.2. Nevertheless, it is very difficult to determine the impact by night station specific. This is because of the huge uncertainty in the timetable of the NS. Therefore, it is not possible to schedule less personnel by night. Because of this, the implementation of these solution will not cause a financial benefit. Instead, the NS will have to pay for this change. Nevertheless, the goal of this research is achieved. More cleaning capacity will be gained by cleaning in daytime.

7.2 Discussion

As mentioned before, the analyses in this research are performed on the timetable of the NS. The uncertainty in the timetable is quite high. Because of this high uncertainty, the reality might differ from the outcome of the analyses. This is the hugest con of this research.

Another con of this research, it was needed to make some unrealistic assumptions. In further research this assumptions should be reconsidered.

- It is assumed that every station has only one cleaning location and every cleaning location can be used to clean trains by day. While, in reality, some stations have multiple cleaning locations and some stations cannot be used to perform cleaning activities by day. This will affect the conclusions about the possible cleaning locations.

- It is assumed that every train can be cleaned within 40 minutes. This is not realistic for every train group. Because of this, less trains can be cleaned in reality.
- Also, for the shifting trains solution, it is assumed that every train can only change one time with another train. In reality, it does not matter how often a train would change with another train. Because of this, in reality, the shifting trains solution will cause an even bigger improvement.
- Furthermore, the benefit of the daily cleaning can only be gained if the trains do not have to be cleaned by night. As mentioned, in this research is assumed that this is possible. This is the biggest assumption and still it is unknown if this will be possible in the future. Currently, due to the NS standards and cleaning procedure, it is not possible. Further research has to be done to see if it is possible to not clean trains by night that are already cleaned in day time. It is important to realize that this is necessary to get the benefits of the solutions that this research covers.

7.3 Recommendations

Further research into the timetable would add a lot of value to this research. If the end stations of trains can be predicted the benefits of the solutions can be given station specific. With this it might be possible to schedule less personnel during the night shifts for certain stations. This would be a financial benefit for the NS.

Also, if the NS could center all the trains that are cleaned in daytime at one end station by night. The benefits can all be taken from that station. This increases the benefits of the implementation. Currently, there is no systematic behind the end stations of trains. Further research into the possibility of developing a systematic that centers all the trains that are cleaned by day at one end station, could add a lot of value. This way all the benefits are gained by one specific stations. Because of the huge benefit less personnel needs to be scheduled at that specific station.

Further research into the pollution of trains and the effect on the customer satisfaction is also recommended. With this knowledge, the benefits of cleaning in daytime are clear. It might be necessary to develop a short cleaning routine that is executed by night for trains that are cleaned in daytime, or it might be that these trains do not need additional cleaning. More knowledge in this field creates more insights in the benefits from cleaning in daytime.

It is also advisable to do further experiments for cleaning by day and shifting trains. This way knowledge is gathered about the encountered problems and how to adapt to these problems. Right now the NS is taking this very seriously and is working on several pilot locations.

In this research it is already mentioned a few times that the timetable of the NS is very unreliable. Because of this it is not possible to schedule specific trains in exact time slots in which they can be cleaned. For further research it would be very valuable to spend time on enabling the exact scheduling of trains in specific time slots. This could be a huge benefit for the logistics at the NS.

For the next stage of implementing cleaning in daytime it is necessary to take the costs into account. This research did not focus on the cost aspect, but this is very important. Right now, the NS is mainly focusing on the capacity and the implementation is at small scale. If cleaning in daytime will be implemented nationally the cost aspect needs to be considered.

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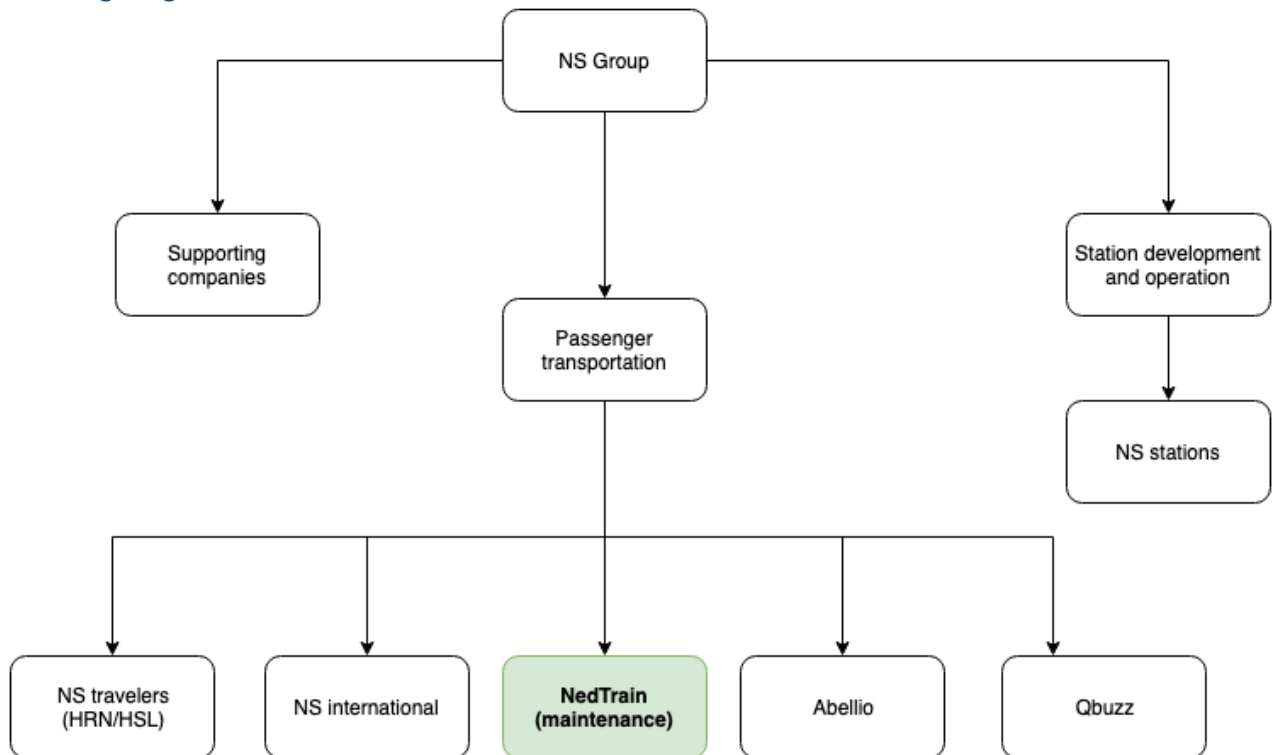
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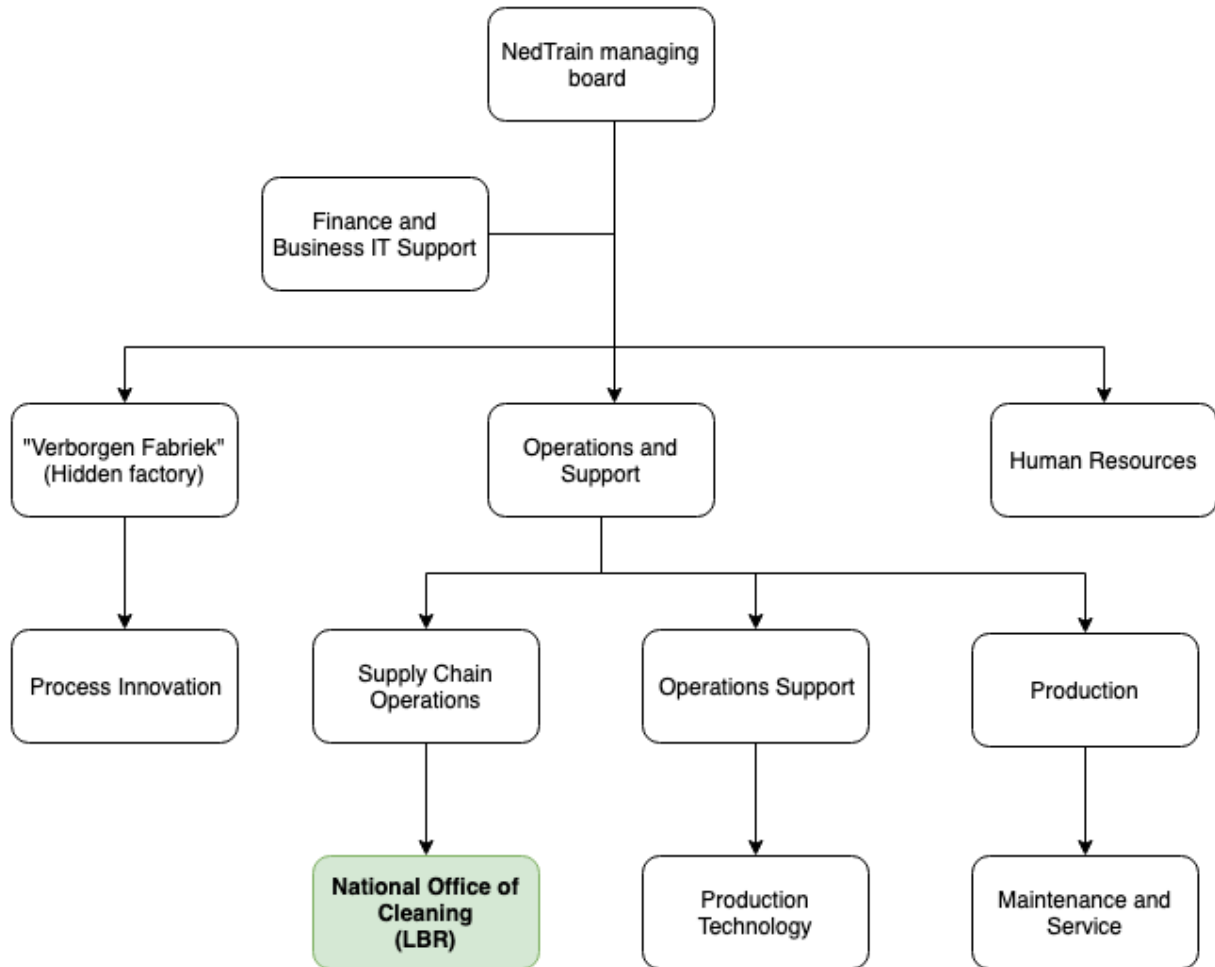
Appendices

A: Organogram of NS and NedTrain

A.1: Organogram of NS



A.2: Organogram of NedTrain



B: The cleaning system

B.1: Criteria for the urgent cleaning of a train

1. Blood and injection needles
2. Feces elsewhere then in the toilet bowl
3. Dirty toilet
4. Heavy odor in passenger and/or staff areas
5. Vomit
6. Broken glass
7. Puddles of liquid on the balcony or in passenger and/or staff areas

B.2: The 45 cleaning locations of the NS

Location	Address
Nijmegen	Thijmstraat 4
Arnhem	Noordelijke Parallelweg 146
Zutphen	Overweg 5a
Enschede	Stationsplein 33
Hengelo	Waarbekenweg 2a
Zwolle	Parallelweg 2
Zwolle	Hanzelaan 345
Zwolle	Stationsplein 16
Leeuwarden	Hollanderdijk 2
Groningen	Hoornsediep 2
Onnen	Felland 1
Amsterdam Centraal	Stationsplein 15
Haarlem	Stationsplein 1 (spoor 4)
Haarlem	Verspronckweg 63VL
Alkmaar	Wognumsebuurt 18
Alkmaar	Stationsweg 4 (Spoor 1)
Amsterdam Watergraafsmeer	Carolina MacGillavrylaan 3402
Almere Centrum	Stationsplein 27
Lelystad Opstel	Houtribweg 60
Lelystad Centrum	Stationsplein 9
Amsterdam Zaanstraat	Transformatorweg 1
Hoorn	Stationsplein 1
Enkhuizen	Stationsplein 1
Den Helder	Parallelweg 4
Hoofddorp Opstel	Bennebroekerweg 475
Hoofddorp Midden	Mercuriusplein 30
Rotterdam	Proveniersplein 25
Den Haag Binckhorst	Binckhorstlaan 60
Den Haag CS	Koningin Julianaplein 10
Leidschendam	Westvlietweg 4
Utrecht Post OZ	Mineurslaan 20
Utrecht Cartesiusweg	Locomotiefstraat 100
Utrecht Landstraat	1e Daalsedijk
Amersfoort Bokkeduinen	Sportpark Bokkeduinen 2
Dordrecht	Stationsplein 1
Utrecht CS	Stationsplein 1
Breda	Stationsplein 16
Eindhoven	Fuutlaan 2c
Eindhoven	Station perron 4
Heerlen	Stationsplein 1
Heerlen	Mijnmuseumpad 3
Vlissingen	Stationsplein 3-5
Maastricht	Nieuweweg 35
Roosendaal	Stationsplein 1
Venlo	Kaldenkerkerweg 28a

B.3: The definition of a clean train:

A train is labeled as clean if it satisfies the quality requirements for category 1 and category 2.

Category 1:

- Trashcans free of dirt
- Water filled (if applicable to equipment)
- Floor – sweep dirt free
- Sanitary (if applicable to equipment) dirt and stain free
- Sanitary ware
- Staff space

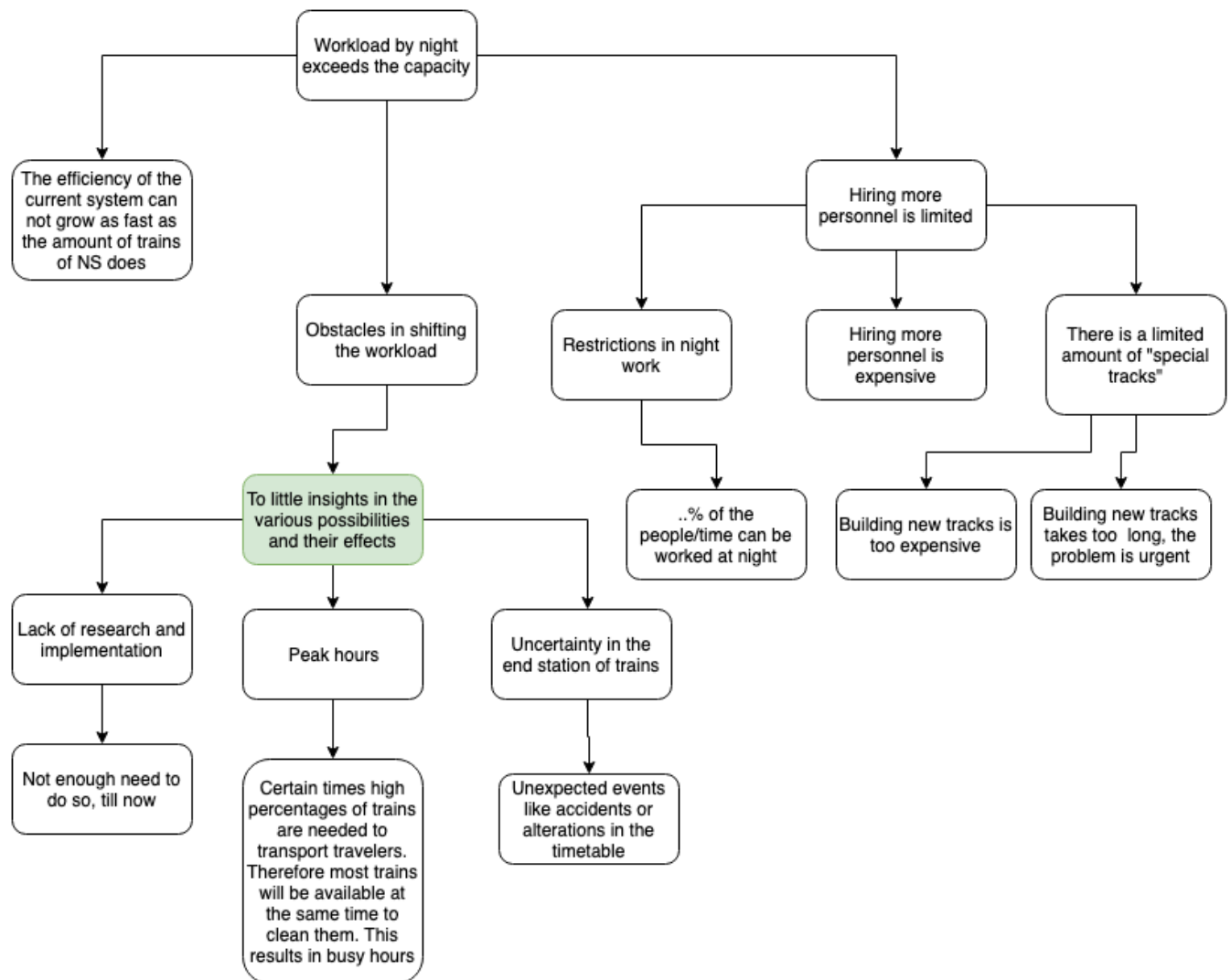
Category 2:

- Floor – stain free
- Floor – free of gum
- Wall – stain free
- Windows – stain free
- Seating environment – stain free
- Balcony – free of dirt

Stain free : free of stains/dirt spots of fingers/slightly attached dirt.

Free of dirt : free of loos/slightly attached/heavily attached dirt.

C: Problem cluster



D: Experiments



This are pictures that show the pollution of a train during day time. This train was cleaned by day, this the state in which the train arrived by night.

E: The end stations of the trains that can be cleaned by day

Monday

Stations	Shifting trains	Daily excess
Asd	1	
Ut	12	8
Mt	1	
Hdr	1	
Wgm	1	
Hgl	1	1
Gn	3	2
Llso	2	2
Gv	3	3
Bkh	1	1
Zl	2	2
Ledn	1	1
Hfdo	1	1
Amr	2	
Rtd	3	1
On	1	
Rsd	1	
Zp	2	

Tuesday

Stations	Shifting trains	Daily excess
Hn	1	
Ehv	2	
Mt	2	
Hfdo	2	2
Rsd	2	1
Ut	7	5
Bkh	2	1
Zl	2	1
Amr	2	
Rtd	3	1
Lw	1	
Gn	1	
Asb	1	
Zpge	1	

Wednesday

Stations	Shifting trains	Daily excess
Lw	1	1
Gn	1	1
Zpge	1	1
Rtd	3	1
Amr	2	
Ut	3	2
Gv	1	1

Thursday

Stations	Shifting trains	Daily excess
Gn	2	1
Rtd	4	1
Amr	2	
Ut	4	4
Zl	1	1
Gv	3	2
Lw	4	3
Wgm	2	1
Ehv	2	
On	1	
Mt	1	
Aswplz	1	
Wt	1	
VI	1	
Nm	1	
Es	1	1
Hfdo	1	1
Bkd	2	2
Bkh	1	1
Ht	1	
Rsd	1	
Zpge	1	

Friday

Stations	Shifting trains	Daily excess
Ehv	3	2
Amr	4	2
Rtd	3	1
Bkd	4	1
Ut	3	
Ekz	1	
Mt	1	1
Hdr	1	1
VI	1	1
Hgl	1	
Hfdo	1	1
Es	2	
Wt	1	1

F: Decision support tool manual

This manual briefly describes how to use the decision support tool. The tool consists of ten sheets in excel. This manual goes through every sheet and briefly explains how to use the tool. If anything is unclear have a look at chapter 6.2. In this chapter every sheet is explained more thoroughly.

Input data

Make sure that the decision support tool is supplied with the right input data. If you need to supply the tool with new data, have a look at chapter 6.1.

VVGB_NedTrain_09062019

This sheet contains the input data of the solution support tool and this data is used to perform the analyses. Every row displays a ride of a train.

AmountOfTrains

Figure 1 displays a screenshot of this sheet. If the button, Calc amount of trains, is pushed, the sheet creates a list of all the trains in the system and calculates the total amount of trains. The list of trains is represented in column A, blue square. The amount of trains is shown at the right of this column, indicated by the yellow circle in figure 1.

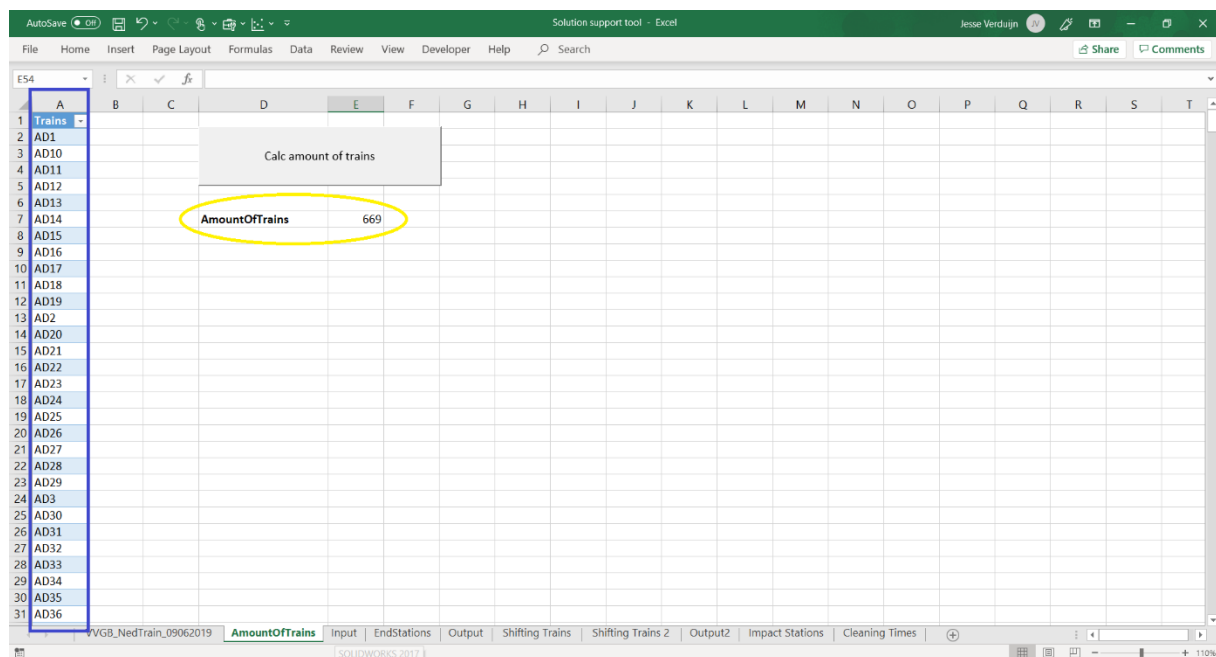


Figure 24: AmountOfTrains

Input

In this sheet the user can choose several input variables for the data analysis.

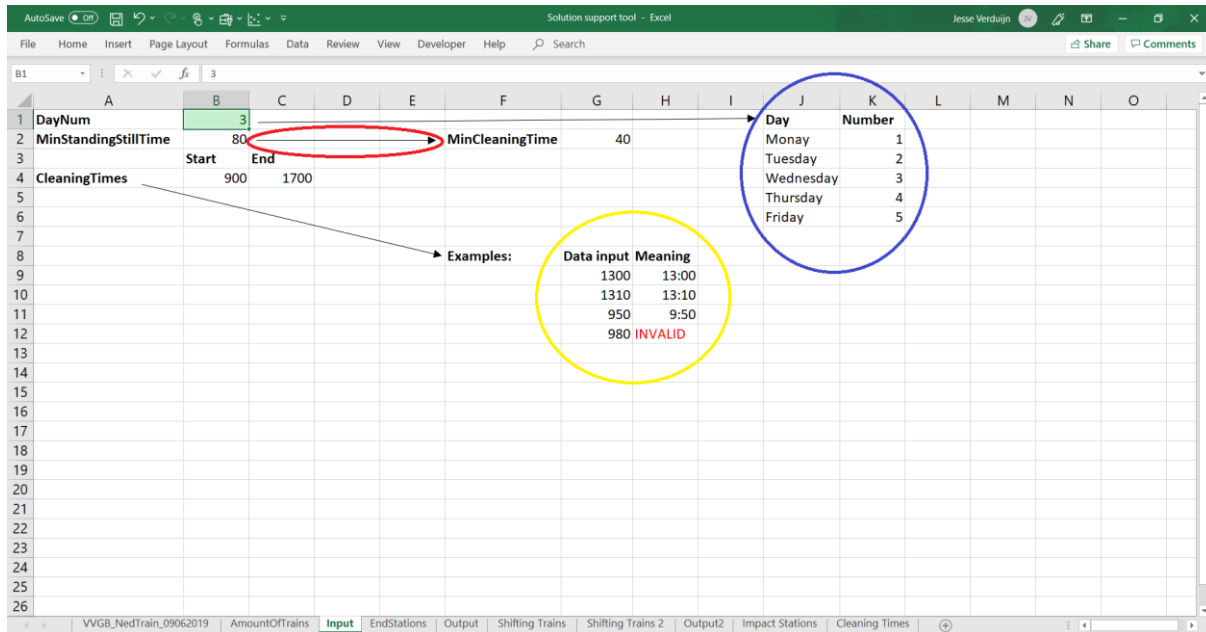


Figure 25: Input

As figure 2 indicates, there are four input variables for the user to choose:

- **DayNum**
With this variable you choose the day to analyze. Every day has his own number and the index is shown in columns J and K (Figure 2, blue circle).
- **MinStandingStillTime**
With this variable the user can tell how long a train minimally needs to stand still to be able to clean it, in minutes. As the arrow (Figure 2, red circle) indicates, the MinCleaningTime (minimal cleaning time) is dependent on this variable.
- **CleaningTimes Start & End**
With the variables CleaningTimes Start & End, the user can indicate between which times the cleaning activities will take place. The format of the input data for this variable is integer. The time expression is the same as used in the army, for example 13:00 is 1300. In the sheet there are some more examples (Figure 2, yellow circle).

EndStations

The function of this sheet is to analyze the end stations and end times of the trains for the chosen day in the sheet “input”.

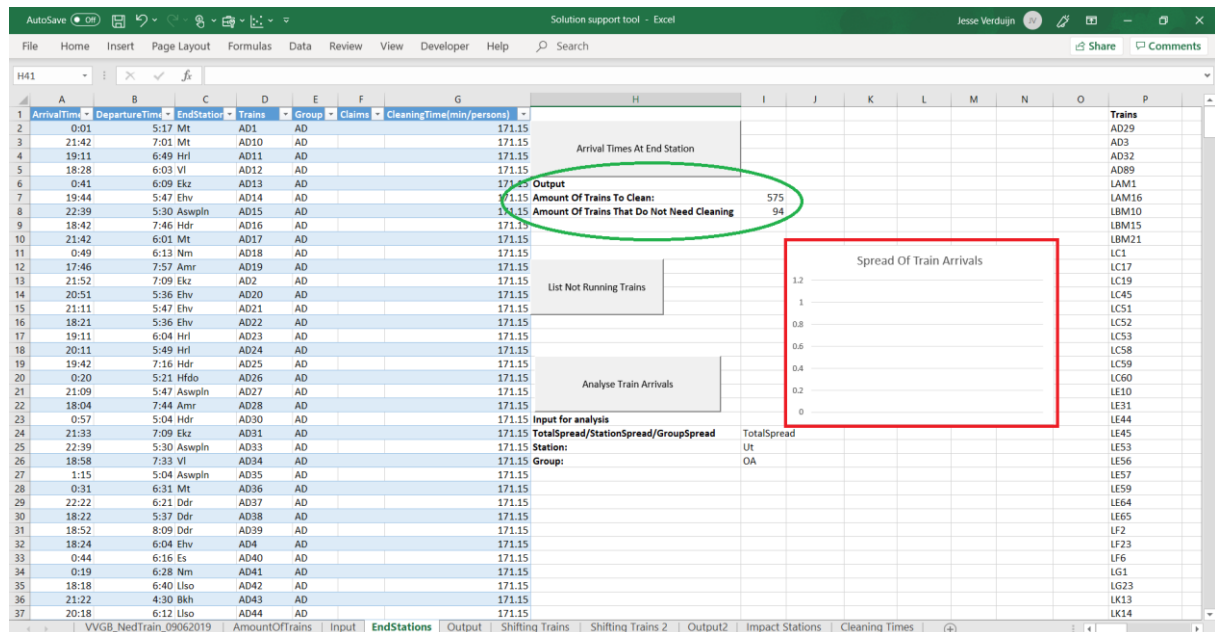


Figure 26: EndStations, List Not Running Trains

This sheet contains three buttons, see figure 14:

- *Arrival Times At End Station*

If this button is pushed, the data in the table at the left of the button (column A till G) is refreshed. The output variables below the button (Figure 3, green circle) will also be refreshed.

- *List Not Running trains.*

Figure 3 displays the layout of the sheet if this button is pushed. The function of this button is to list all the trains that do not need to be cleaned. The list of trains will be displayed in column P. Furthermore, this button empties columns K and L. Therefore, the figure in this sheet (Figure 14, red square) is not displaying any useful information if the button is pushed.

- *Analyze Train Arrivals.*

To explain the function of this button figure 4 will be used. If this button is pushed the table (Figure 4, red circle) will be created or refreshed. The figure below the table displays the content of the table visually. Below the button (Figure 4, blue square) the user can choose several input variables for the analysis. For the first input variable, the user can choose TotalSpread, StationSpread or GroupSpread.

- If TotalSpread is chosen, the distribution of the workload of all the trains will be shown. The variables “Station:” and “Group:” will not be used if this option is chosen.
- If StationSpread is chosen, the variable “Station:” should also be filled with the station to analyze. The distribution of the end times of all the trains with the chosen end station will be shown.

- If GroupSpread is chosen, the variable “Group” should also be filled with the group to analyze. The distribution in of the end times of all the trains that are part of the chosen group will be shown.

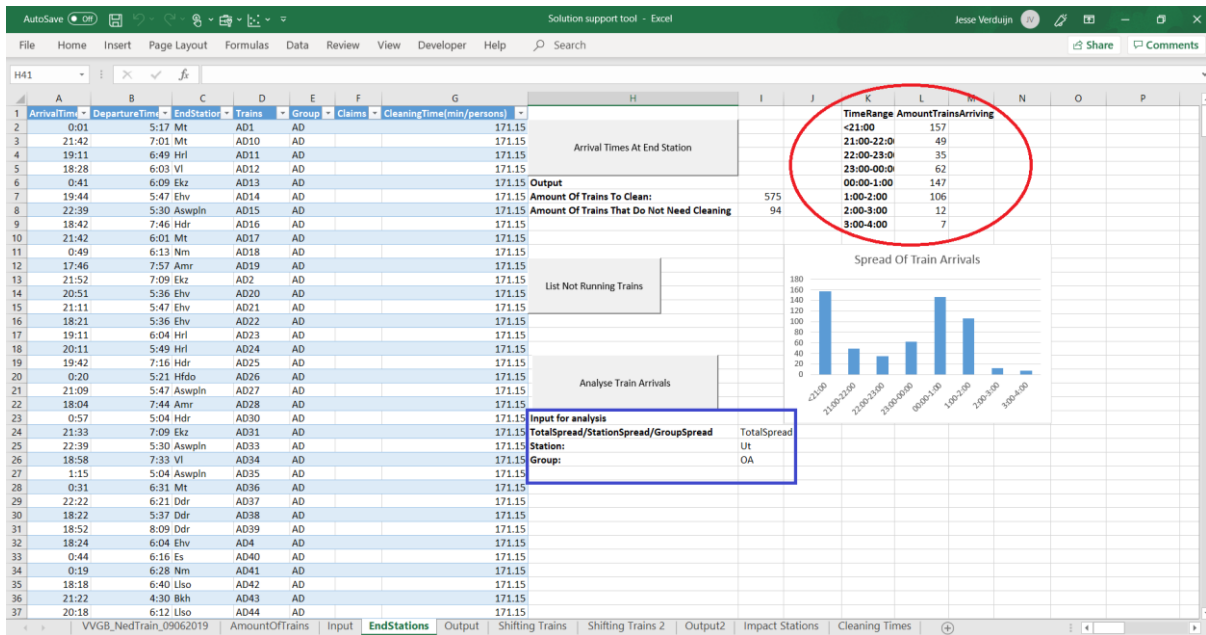


Figure 27: EndStations, Analyze Train Arrivals

Output

The function of this sheet is to show the possibilities and the potential of using the daily excess with the chosen input variables in the sheet “Input”.

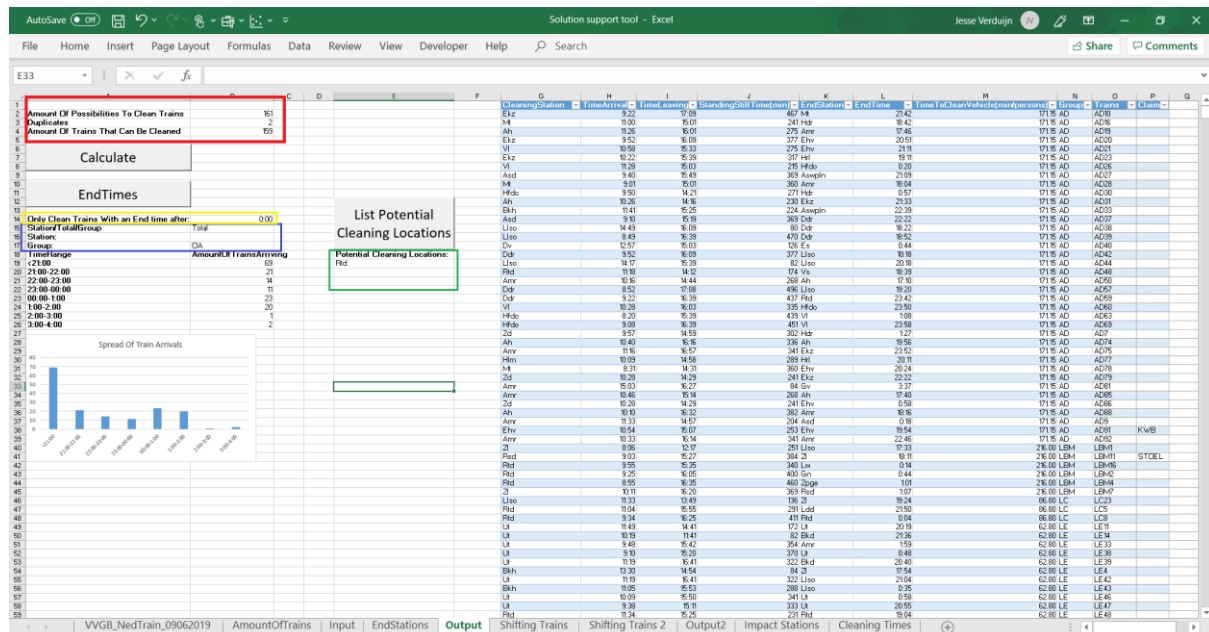


Figure 28: Output

The sheet contains three buttons (Figure 5):

- **Calculate**

This function calculates three output variables for the possibilities of using the daily excess: the amount of possibilities to clean trains, the duplicates and the amount of trains that can be cleaned. These output variables can be found above the button (Figure 5, red square).

This function refreshes the content of the table at the right side of the sheet (columns G till P). Every row in the table is a possibility to clean a train.

- **EndTimes**

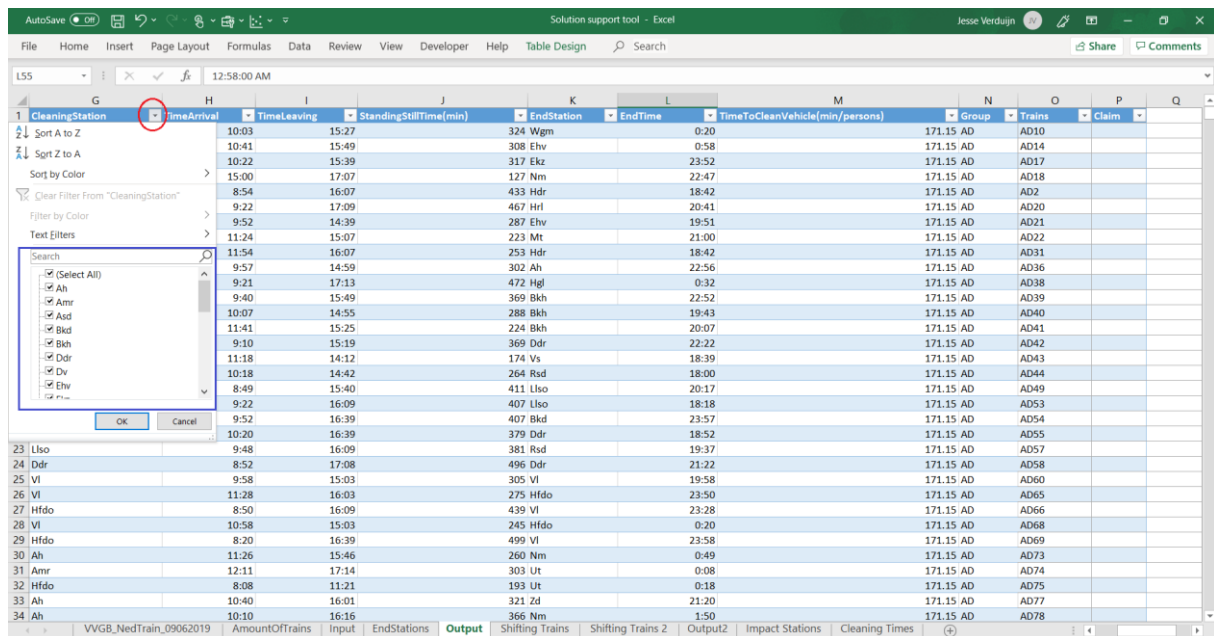
Below the button (Figure 5, blue square) there are several options to choose for the analysis. This basically is the same function as the button “Analyze Train Arrivals” in the sheet “EndStations”, described earlier in this manual. The only differences are the input data and the three options are now called Station, Total and Group instead of StationSpread, TotalSpread and GroupSpread. Just like the function “Analyze Train Arrivals”, the output is displayed in a table as well as in a figure. The table and the figure are displayed below the input variables.

- **List Potential Cleaning Locations**

For this function one input variable can be chosen (Figure 5, yellow square), “Only clean trains with an end time after:”. This input variable allows the user to target a certain group of trains. For example, if 22:00 is chosen, only trains with an end time between 22:00 and 4:00 are cleaned. The potential cleaning location(s) will be listed below the button (Figure 16, green square).

The use of the table in the sheet Output

Now that the potential cleaning location(s) are known the table can be used to show all cleaning possibilities for these stations. To do so click on the right side of the column header of “CleaningStation” (Figure 6, red circle) and then select the potential cleaning stations (Figure 17, blue square).



CleaningStation	TimeArrival	TimeLeaving	StandingStillTime(min)	EndStation	EndTime	TimeToCleanVehicle(min/persons)	Group	Trains	Claim
Sort A to Z	10:03	15:27		324 Wgm	0:20		171.15 AD	AD10	
Sort Z to A	10:41	15:49		308 Ehw	0:58		171.15 AD	AD14	
Sort by Color	10:22	15:39		317 Elkz	23:52		171.15 AD	AD17	
Clear Filter From "CleaningStation"	15:00	17:07		127 Nm	22:47		171.15 AD	AD18	
Filter by Color	8:54	16:07		433 Hdr	18:42		171.15 AD	AD2	
Text Filters	9:22	17:09		467 Hrl	20:41		171.15 AD	AD20	
	9:52	14:39		287 Ehw	19:51		171.15 AD	AD21	
	11:24	15:07		223 Mt	21:00		171.15 AD	AD22	
	11:54	16:07		253 Hdr	18:42		171.15 AD	AD31	
	9:57	14:59		302 Ah	22:56		171.15 AD	AD36	
	9:21	17:13		472 Hgl	0:32		171.15 AD	AD38	
	9:40	15:49		369 Bkh	22:52		171.15 AD	AD39	
	10:07	14:55		288 Bkh	19:43		171.15 AD	AD40	
	11:41	15:25		224 Bkh	20:07		171.15 AD	AD41	
	9:10	15:19		369 Ddr	22:22		171.15 AD	AD42	
	11:18	14:12		174 Vs	18:39		171.15 AD	AD43	
	10:18	14:42		264 Rsd	18:00		171.15 AD	AD44	
	8:49	15:40		411 Liso	20:17		171.15 AD	AD49	
	9:22	16:09		407 Liso	18:18		171.15 AD	AD53	
	9:52	16:39		407 Bkd	23:57		171.15 AD	AD54	
	10:20	16:39		379 Ddr	18:52		171.15 AD	AD55	
	9:48	16:09		381 Rsd	19:37		171.15 AD	AD57	
	8:52	17:08		496 Ddr	21:22		171.15 AD	AD58	
	9:58	15:03		305 Vi	19:58		171.15 AD	AD60	
	11:28	16:03		275 Hfdo	23:50		171.15 AD	AD65	
	8:50	16:09		439 Vi	23:28		171.15 AD	AD66	
	10:58	15:03		245 Hfdo	0:20		171.15 AD	AD68	
	8:20	16:39		499 Vi	23:58		171.15 AD	AD69	
	11:26	15:46		260 Nm	0:49		171.15 AD	AD73	
	12:11	17:14		303 Ut	0:08		171.15 AD	AD74	
	8:08	11:21		193 Ut	0:18		171.15 AD	AD75	
	10:40	16:01		321 Zd	21:20		171.15 AD	AD77	
	10:10	16:16		366 Nm	1:50		171.15 AD	AD78	

Figure 29: Output, cleaning location

Shifting Trains

The functions of this sheet directly perform their calculations for the whole week.

Figure 30: Shifting Trains

The table at the left of figure 7 (column A till G) displays all the events where trains from the cleaning location can be changed with trains that arrive at the station. This table is refreshed by the button “List Potential Trains To Change”.

The table at the right of figure 7 (starting at column M), displays every train that arrives at a station and can be changed with a train at a cleaning location. The content of this table is refreshed by the button “Possible Changes”. The input variable of this function is the MinTimeToShift (Figure 7, red circle).

With the variable “MinTimeToShift” the user can choose the minimal time a train needs to stand still at a station to change it with a train from the cleaning location.

The button “Create Schedule” is provided with a heuristic that chooses which possible changes, from the table at the right of the sheet, are executed. For this function there are three input variables that can be chosen (Figure 7, blue circle):

- *Only schedule trains with end time after:*
This way the user can target a specific group of trains. Only trains with an end time after the chosen time, will be considered.
- *Filter trains with daily excess:*
Some of the trains with a possibility to change, also have the possibility to be cleaned during the current daily excess. If the user wants to exclude this trains from the changing possibilities, this is possible. For the input “Yes” these trains will be filtered, for “No” these trains will not be filtered.
- *Specific station:*
If the user wants to see the possible changes for one station only, the abbreviation of the desired station should be used as input variable. With this option the sheet

“Shifting trains 2”, will be filled only with possible changes for this specific station. If the input cell is left blank, the function will list all possible changes in “Shifting trains 2”.

Shifting Trains 2

This sheet contains a big table. Every row is a train that goes to a cleaning location because of a change with another train.

The screenshot shows an Excel spreadsheet with a large table containing train data. The columns include: CleaningStation, TimeArrival, TimeLeaving, StandingTime, EndStation, EndTime, TimeToCleanVehicle/person, Group, Trains, Claims, OriginalDep, OriginalEnd, OriginalRef, Train, Time, Day, and a final column for 'Merge Solutions' which is highlighted with a red box. The table lists various train movements between stations like '144 ZI', '111 Ut', and '111 Rnd'.

Figure 31: Shifting Trains 2

The only button in this sheet is “merge solutions” (Figure 8, red square). The function of this button is to merge the table of “Output” with the table in the sheet “shifting trains 2” into one table in “Output 2”. This way the sheet “Output 2” presents the same data as the sheet “Output”, but now with the executed train changes added.

Output 2

This sheet has almost the same layout as the sheet “output”. The functions “list potential cleaning locations” are the same in both sheets. The function “EndTimes” in “Output” is exactly the same as the function “Impact Of Shifting Trains” in “Output 2”. The only difference is that in this sheet all output variables are compared to the output variables in “Output”. In figure 9, the blue squares are the values with the extension of shifting trains and the red squares are the values for only using the daily excess. The table and the figure in column A till C, show the deviation of train arrivals for the shifting train solution and the added value of shifting trains (Figure 9, pink square). The input variables in the sheet “Output” are exactly the same as in this sheet.

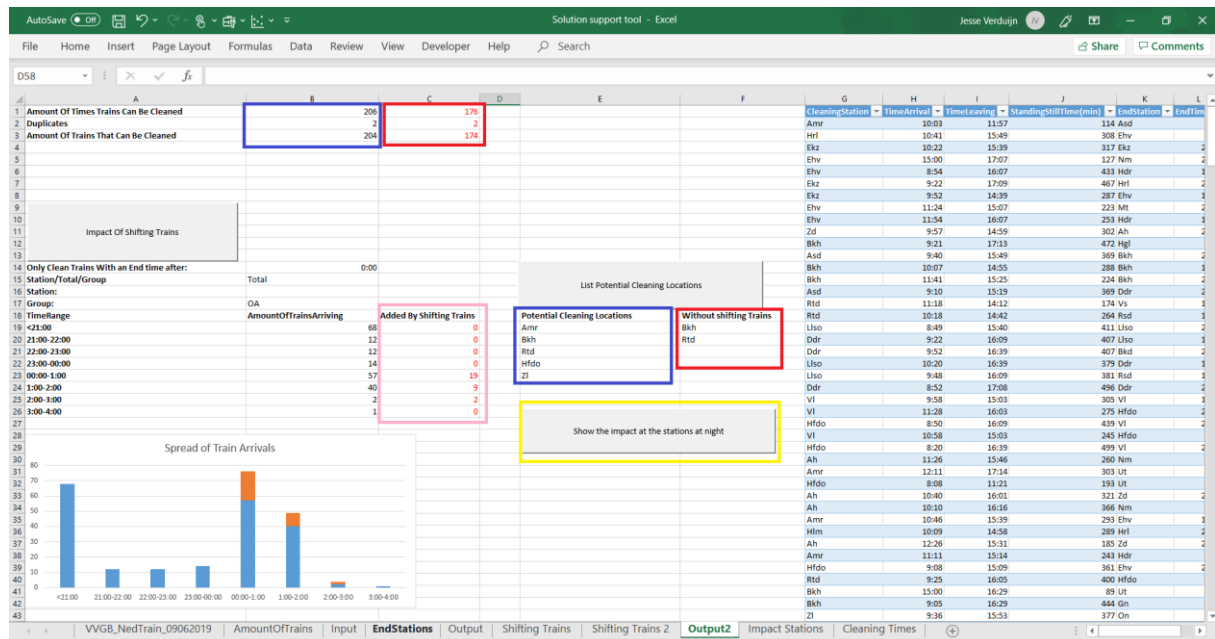


Figure 32: Output 2

This sheet contains one button with another function then in the sheet “output” (Figure 9, yellow square). If this button is touched the sheet “Impact Stations” is refreshed and opened.

Impact Stations

The table in this sheet shows the end stations of the trains that can be cleaned by day and how many of these trains end at these stations. The results of daily excess and shifting trains are displayed next to each other to be able to see the added value of shifting trains. The same data is also displayed in a figure next to the table. Furthermore, the sheet shows two output variables (Figure 10, red circle): total shifting trains and total daily excess. Both variables show how much trains of the target group, can be cleaned by day using the potential cleaning locations.

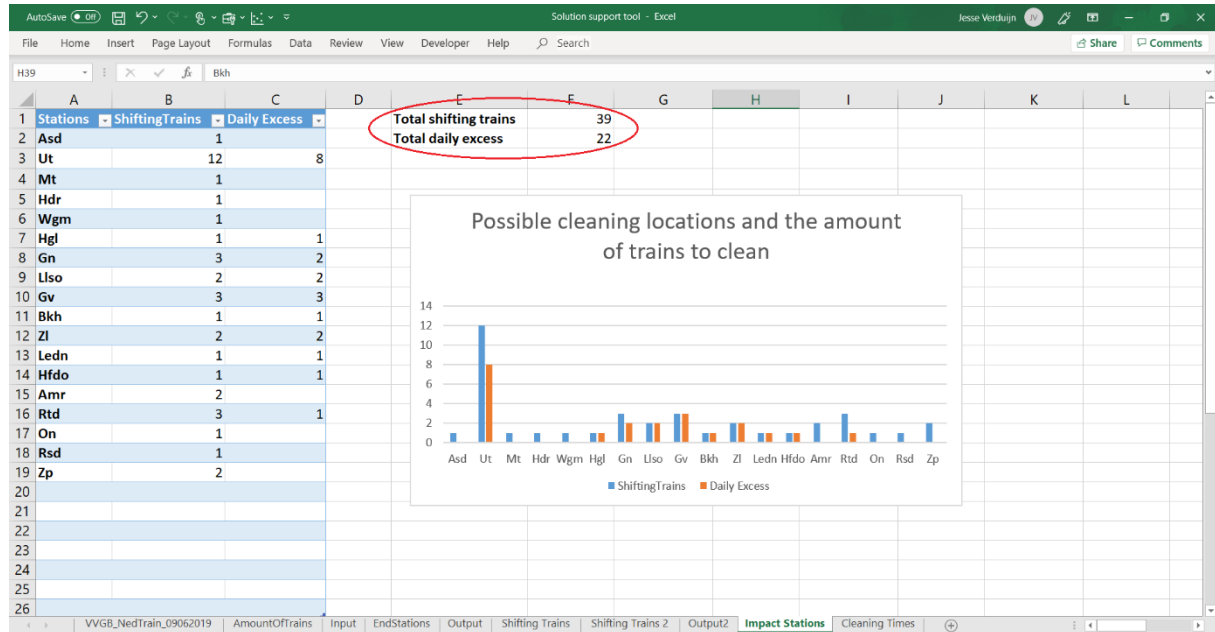


Figure 33: Impact Stations

Cleaning Times

This sheet contains the information about the cleaning times for every group of trains. Only trains that are part of one of the train groups of which this sheet contains information, are considered in the analyses of the tool.