UNIVERSITY OF TWENTE.

ProRail

Allocation and scheduling of incident general leaders at ProRail

Bram van Uden

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Allocation and scheduling of incident general leaders at ProRail

Author:
B.W. van Uden (Bram)
b.w.vanuden@student.utwente.nl
s2082799

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ProRail

Moreelsepark 3
3511EP Utrecht
0800 7767245

University of Twente

PO Box 217
7500AE Enschede
+31(0)534899111

Supervisors ProRail
Mrs. S. Wevers (Saskia)
Mr. E. Hueting(Edward)

Supervisors University of Twente
DR. A. Trivella (Alessio)
DR. IR. L.L.M. van der Wegen (Leo)

Preface

Dear reader,

You are about to read my thesis “Allocation of ALs at ProRail with the use of continuous simulation”. This research has been conducted at ProRail to complete my Bachelor’s degree in the program Industrial Engineering and Management at the University of Twente (UT).

I would like to thank my main supervisor from the UT, Alessio Trivella. His effort to support me with feedback and thinking along helped me a lot during my research. Even though the research took longer than expected, he always supported me which I highly value! Also, I would like to thank Leo van der Wegen as my second supervisor from the UT for his time, critical eye and advices.

From ProRail, I would like to thank all people that contributed to my research. A special thanks goes to Edward Hueting and Saskia Rademaker. I highly appreciate their support, sharing of insights, and the experience I got out of my research at ProRail. Lastly, I want to show my gratitude to my family and friends who have supported me.

Enjoy reading my Bachelor thesis.

Kind regards,
Bram van Uden
Enschede, May 2023

Management summary

ProRail is assigned by the government of the Netherlands to take care of maintenance and extensions of the national railway infrastructure. One department of ProRail deals with incidents on the railway track. Their goal is to repair or clear the infrastructure after an incident has occurred as fast as possible, to get the least amount of hindrance for the users of the tracks. Due to the high costs associated with the incidents, optimizing the handling of incidents is highly needed to ensure fast and safe traveling. ALs (short for 'Algemeen Leiders) coordinate the process to resolve an incident. Currently, there are 6 ALs, located at assumingly logical places. The choice for these locations is not based on collected data. This means there is an unused potential in allocating ALs to improve over the current AL allocation by using data analysis and modelling.

Based on this problem, the main research question is formulated as 'How should the ALs be allocated, based on provided data, to lower their travel times below 45 minutes in 95% of the time, taking the utilization of their work shifts into account?' Four KPIs are chosen, namely the average time an AL needs to arrive at the place of the accident, the number of times an AL needs more than 45 minutes to arrive at the place of incident, the utilization of ALs, and the number of times there are not enough ALs available. The current situation is analyzed based on the KPI scores derived from the data. With an average travel time of 51.8 minutes and more than half (52.9%) of the incidents with a travel time higher than 45 minutes, the current situation is not reaching the goal of travel times below 45 minutes for 95% of the incidents..
A combination of the CRISP-DM and MPSM models is used as a research model for the research question.

Based on the research model, literature research is conducted to find a suitable method to allocate ALs. A continuous simulation is chosen to replicate the allocation of ALs. This simulation is based on the dispatching rules ProRail uses with 'Slim allermeren' (shortly SA). In short, the SA allocates an AL to the closest available AL.

After validating the simulation, a framework is created wherein it is used. Based on conversations with ProRail, there is a selected number of options to vary the stationary locations and the number of ALs. This means the search space is static, because only a limited number of different simulations can be run. These simulations are categorized into 6 scenarios, each with multiple different simulations (called runs). The simulation, together with the framework, is called the simulation Allocation Tool (SAT).

After collecting the KPI scores for all the run, the runs (within each scenario) are compared. The dominated options are eliminated and the best runs of each scenario are compared to the scores of the current allocation. Based on these comparisons, conclusions are drawn on how to improve the AL allocation.

In none of the runs the goal of a maximum travel time of 45 minutes in 95% of the incidents was reached. However, taking the limitations of the research and the SAT into account, certain changes would help to reach this goal. The main finding is the potential of opening a new location around Arnhem with an extra AL. This will significantly improve the allocation of ALs, decreasing the average travel time to 42,6 minutes, and the travel times larger than 45 minutes to 34,1% of the incidents. To reach the goal, even more ALs and/or more new locations are needed. This is beyond the indicated possibilities, wherefore this is not explored.

For further research it is advised to look into the way ALs are dispatched. Currently the SA, together with manual changes, allocates the ALs. Adding dispatching rules to the SA will make this system more intuitive. The main limitation of this research is the difference between the actual and simulation KPI scores. This is (partially) due to allocations based only on the SA dispatching rule. Simulating a more intuitive SA will decrease this difference.

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List of acronyms

AL	Algemeen Leider/'General leader'
BO	Back Office
CATO	Cameratoezicht/Camera surveillance
CHI	Coördinator Herstel Infra/'Coordinator Repairing Infrastructure'
ICB	Incidenten Bestrijding/'Incident Handling'
LVL	Landelijk Verkeersleider/'National Traffic Leader'
MBN	Materieel Bijsturingscentrum NedTrain/'Material Supportcenter NedTrain'
MKS	Meldkamer Spoor/'Control Room Trail Tracks'
OCCR	Operationeel Controle Centrum Rail/'Operational Control Center Train Tracks'
OVD-A	Officier Van Dienst – Assets/'Shift Officer Assets'
OVD-I	Officier Van Dienst – Incidenten/'Shift Officer Incidents'
OVD-S	Officier van Dienst – Spoor/'Shift Officer Trail Track'
PL	Ploeglid/'Crewmember'
PLL	Ploegleider/'Crew leader'
PLBO	Procesleider Besturing Operatie/'Officer Operation Control'
SA	Slim Alarmeren – Smart Alarming
SAT	Simulation Allocation Tool

1. Introduction

The first chapter introduces ProRail, the problem formulated by ProRail, and the steps to solve this problem. Step-by-step it explains how the research is designed and conducted. Section 1.1 provides a company description followed by the research motivation in Section 1.2. The problem ProRail is dealing with is explained in Section 1.3 and a suitable problem-solving approach is covered in Section 1.4. The chapter concludes with the deliverables for ProRail in Section 1.5.

1.1 Company description

The introduction of ProRail is split up in two parts. The first part is the general company description, to indicate the field ProRail is operating in. The second part provides insight into the information flow of the incident department by an operational overview.

1.1.1 General company introduction

ProRail is assigned by the government of the Netherlands to take care of maintenance and extensions of the national railway infrastructure (*Wat wij doen*, 2022). Their headquarters are located in Utrecht. Together with the railway operators, ProRail is responsible for safe and timely travel of passengers.

There are many departments within ProRail: track maintenance, track renovation, capacity allocation, train traffic coordination, soil investigation, rail freight transport and incident handling. To execute the processes of each department, ProRail is constantly changing and innovating. Projects like adding tracks in 's-Hertogenbosch or sustainable rail transport in Alkmaar are examples (ProRail, 2023)

As indicated, a part of ProRail deals with incidents on the railway track. Their goal is to repair or clear the infrastructure after an incident has occurred to get the least amount of hindrance for all users of the tracks. ProRail has 6 stationary locations from where teams can be sent to solve incidents. These can range from a broken railroad crossing to an accident involving civilians. All the needed information is reported to the OCCR (OCCR and Operational Control Centrum Rail) and forwarded to the local stations to act accordingly. Due to high costs associated with the incidents, optimizing the handling of incidents is highly needed to ensure fast and safe traveling.

1.1.2 Operational overview

Lots of money and people are involved when an incident occurs. Therefore, an overview of the operations within ProRail provided. Figure 1 shows the overview of the operations of the incident handling department ("Incidentenbestrijding", or ICB). It shows the information flow from the start of the incident handling, up to the end. See Appendix E for a more detailed overview.

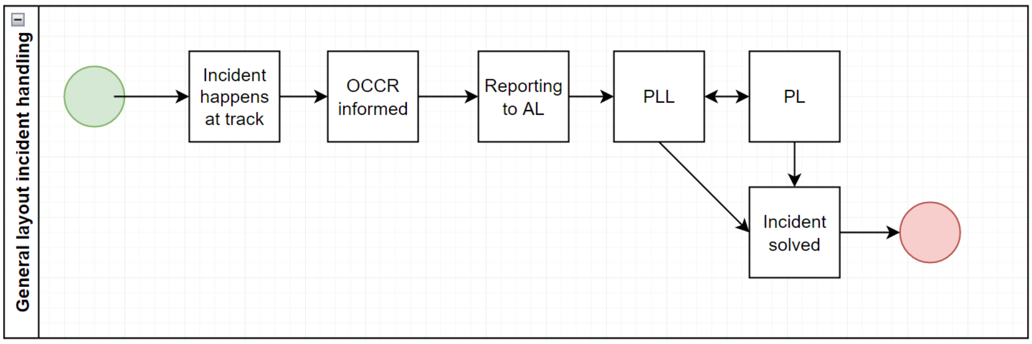


Figure 1: Overview ICB

When an incident occurs, the OCCR is updated first. For example, the incident can be reported by train operators, governance agencies or pedestrians. The OCCR is the place where all main personnel concerning incident handling are located. Within the OCCR there is an extensive division of tasks. For example, the MKS (Trail Tracks Control Room) receives all incidents and correctly files them in the ProRail information system called Spoorweb. After this step, others involved start their tasks.

To solve the incident, a team is sent. This team has a PLL ('Crew leader': leader of the team solving an incident) and others helping him, PL (crewmembers). The OVD-I ('Shift Officer Incidents': officer of the incidents and part of the OCCR) will send a request, and the most suited AL ('General leader': coordinates everything around the incident) is informed. The ALs are located at six stationary locations. They lead the overall process of sending the team, alerting the right persons, etc. They form the connection between the OCCR and the team that solves the incident. A lot of parties are effected when an incident occurs on the train tracks. Therefore, the role of the AL is key to guide the process efficiently and effectively. When the incident is solved, the operations of traffic can return to their normal state.

Spoorweb is of high essence in communication between all involved parties. All the updates to the incidents are reported here, together with the progress updates. It ensures proper handling of all stakeholders accordingly.

1.2 Research motivation

The usage of train services in the Netherlands is very high. When travelling by bike or foot is not possible, the train is the way of transportation that is counted on lots of times. That is why ensuring timely arrival of trains, by keeping them schedule, is important. It is very unfortunate when an incident happens at the track and influences the travel of the passenger (and cargo). By helping ProRail to make sure incidents are handled efficiently timewise, the passengers are expected to be hindered less. This brings the benefit of fewer external effects, resulting in higher satisfaction for all stakeholders.

Next to contributing (indirectly) to the satisfaction of passengers, the research outcomes will give ProRail better insight into their allocation. If the effectiveness of the solution turns out to be high, similar researches can be applied to different cases, helping ProRail even further.

1.3 The Problem

After the company description and the motivation are clear, the problem ProRail faces is defined. It includes the steps of formulating the problem statement and finding the core problem.

1.3.1 Problem statement

To define the problem statement, the current situation is described. (Section 2.1 explains this in more detail.) Currently, the available ALs are allocated based on intuition and the 'Slim Alarmeren' (Smart Alarming, or SA) tool. The SA tool allocates the closest available AL to the incident. ProRail faces the issue that the current allocation of ALs causes travel times to be longer than their target of 45 minutes. Incidents on train tracks happen all over the Netherlands and their time, place, and gravity are impossible to predict. Fortunately, ProRail keeps a data record of all the incidents and the corresponding information. Currently, this data is not used to predict the need for ALs for each station. This brings multiple problems, starting with longer travel times for the ALs. Especially the longer travel causes less smooth and efficient handling of the ALs. In its turn this leads to dissatisfaction of passengers and higher costs. ProRail strives to the best travel experience for all their users. This means the allocation of the ALs is part to achieve this goal.

To achieve this goal, a quantitative research approach is used for the allocation of the ALs. Quantitative research establishes statistically significant conclusions by studying a representative sample of an event (Lawhorn, G. L., 2007). The data provided by ProRail, that includes the details of incident handling, will form a basis to analyse the current situation. It is also of purpose to find out what an improved situation would look like. This view of reallocation with to decrease travel time has a positive impact on two stakeholders:

ProRail. As a company responsible for incident handling, timely solving is of great importance to their reputations as a company. They are responsible for the possible consequences that come with a delay. Timely incident handling will also save money, because less time and man hours are needed. Within ProRail, there are multiple tasks defined for incident handling as indicated in Section 1.1.2, including:

- ALs. The goal of the AL is to solve the incidents as well and fast as possible. Solving incidents timely logically contributes to this goal.
- PLL. The PLs needs instructions and information during incident handling. Timely arrival of the AL will help to guide the PLL sooner to instruct the PLs.

- PL. When the PLL gets the needed instructions and information sooner, the PLs can perform their job better/quicker.
- OCCR/OVD-I. Since the AL is the link between the PLL and the OVD-I from the OCCR, faster arrival of the AL and so quicker/better communication towards the OCCR is beneficial.

Clients of the tracks. Using the tracks in the way that has been agreed upon by ProRail and the client, without any hindrance, is the ideal situation for the clients of the tracks. Incidents will obstruct this and has consequences. These can range from passengers of NS not arriving on time, or a freight train arriving later than scheduled. The clients of the tracks can be split up into two main categories:

- The railway operators. Railway operators use train tracks to transfer goods or people. NS is an example of a railway operator, for the transportation of people.
- Passengers. With an average of 1.3 million travellers a day (Leblanc, 2021), a large number of people in the Netherlands use train services as their way of transportation. Hinder on the tracks causes delays for passengers, troubling their schedule. Since it concerns a large group of stakeholders, timely operation of incident handling is important for them.

Concluding, reallocation can be highly beneficial to all stakeholders. Therefore, solving the problem is of great value.

1.3.2 Core problem

After defining the problem, the stakeholders, and the motivation to solve it, the core of the problem must be found. It formulates the basics of the problem ProRail is facing. To get to the core problem, a problem cluster is shown in Figure 2. The problem is formulated in collaboration with the supervisors of ProRail.

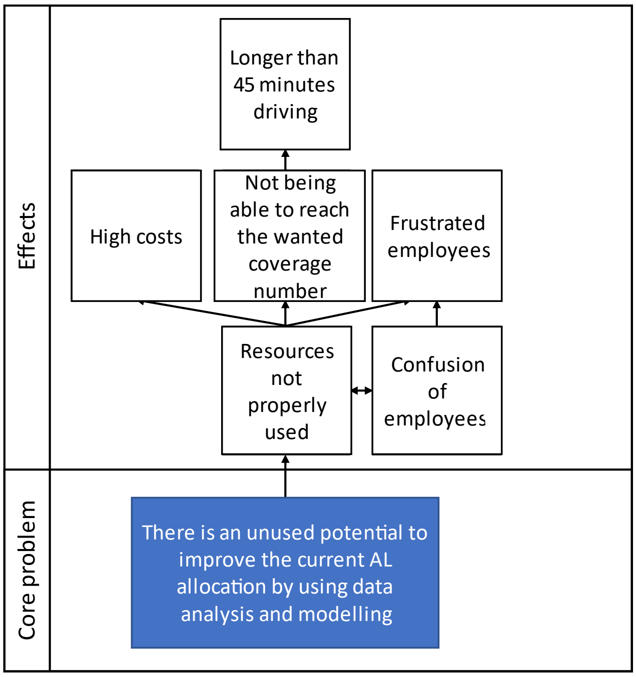


Figure 2: Problem cluster

A main consequence of the unused potential of data analysis and modelling are travel times of ALs being longer than 45 minutes. From the problem cluster the core problem can be formulated as:

'There is an unused potential in allocating ALs to improve over the current AL allocation by using data analysis and modelling.'

This statement follows from the difference between the norm and reality. The first unknown in this statement is the current allocation (**reality**). The current state is more elaborately explained in Chapter 2. This can be measured in the KPIs (Key Performance Indicator), measurable values that demonstrate how effectively a business operation is (What is a KPI?, 2022). The selected KPIs are the average travel time, the number of times the AL needs more than 45 minutes to arrive at the place of incident, the utilization of the ALs and the number of times there are not enough ALs available. The KPIs indicate if the overall goal is met in general, how many times the goal is not met and to what extent the initiated solution is using its resources (ALs) efficiently. This will give a good indication of the current state and to what extent a better allocation solution is needed. Section 1.4.1 explains what these KPIs mean.

The second unknown is defined as the **norm**, i.e. the goal where the reality must move towards. It can be reached by applying data analysis and modelling. Given by ProRail is the goal of reaching the locations of the incidents within 45 minutes. This number should be the minimum threshold to achieve better allocation. It is the norm for the KPI of average time the AL needs to arrive at the place of accident. To the second KPI, the norm is set to decrease the number of unmet arrivals, meeting a satisfaction rate of 95%. The satisfaction rate is based on a discussion with the ProRail supervisor. The third KPI has the purpose to compare the utilization of the ALs for the current state and the new states. The fourth KPI (the number of times there are not enough ALs available) is used to compare new states.

1.4 Problem Solving Approach

After defining the problem clearly, the approach to solving it is formulated. This includes the main research goal followed by a research design that depicts all the steps to take to reach the research goal.

1.4.1 Research Question

The research question can be formulated as:

'How should the incident general leaders (AL) be allocated, based on provided data, to lower their travel times below 45 minutes in 95% of the time, taking the utilization of ALs into account?'

Taking the utilization into account is key to bring a reasonable advice to ProRail. As stated before, by simply allocating more ALs, the travel time most likely will decrease, but it isn't an efficient way of dealing with resources (available work hours of the AL). Therefore taking the utilization into account is very important. This KPI will serve as a criterion to balance the choice between scenarios, based on the other two KPIs. The missing usage of data analysis and models prevents the current state from reaching the norm. Therefore, the goal as stated is applicable to find the solution ProRail is looking for.

To achieve this goal, the question is split up into variables (KPIs). As indicated, KPIs are used to compare the norm and realities between the current and the proposed situation. To construct these, the input from the data, variables to change in a model and outputs from a model are defined.

Inputs

- Date and time of the incidents. To structurally build a model, the time and date of incidents are of essence.
- The time incident operations take. Since the duration of the incident handling influences the number of incidents an AL can go to, the time an incident operation takes is very important.
- The locations of the incidents. Without the location of the incidents, it is impossible to determine the travel times and the ideal allocation of the ALs.

Variables

- The stationary locations of the ALs, where they are currently housed. To determine the travel times, the locations from where the AL must go to the location of incident is key to determine the travel times.
- Number of ALs at a location. To know the capacity of ALs and therefore the number of incidents that can be solved, the capacity is key to know.

Outputs (KPIs)

- The average travel time. To know if the KPI of average travel time is smaller than 45 minutes in 95% of the incidents, the travel times are essential to know. It's the time an AL needs to get from the station to the place of accident.
- The number of times the AL needs more than 45 minutes to travel to the place of incident (also called T > 45). This KPI indicates for how many incidents the norm is met.
- The utilization of ALs. To determine the utilization of the ALs, the times the ALs are not assigned to an incident are of importance. Within these times, the ALs are not occupied with the task to help solving incidents.
- The number of times there are not enough ALs available. It could occur that there are not enough ALs for the number of incidents. This is unwanted wherefore it is important to keep this number in mind when comparing scenarios.

The approach taken to calculate the KPIs is explained in Section 2.3.

The inputs are derived from the data provided by ProRail. To compare the different configurations that the model can have, the variables are changed. The range of the variables is small. When the inputs and variables are determined, the outputs of the model are gathered and KPIs are constructed form a conclusion.

1.4.2 Research methodology

To solve the problem described in Section 1.4.1, the MPSM (Managerial Problem-Solving Method) model by Hans Heerkens and Arnold van Winden is used. It is a general research design model that can be widely used anywhere with an adaptable framework, so that creative and systematic approaches complement each other (Heerkens, H., et al., 2017).
For the case of ProRail, data modelling is key in the formulation of the approach to solve the problem. Therefore, the Cross Industry Standard Process for Data Mining model (CRISP-DM), which describes the data science life cycle (CRISP-DM, 2022), will be used together with the MPSM.

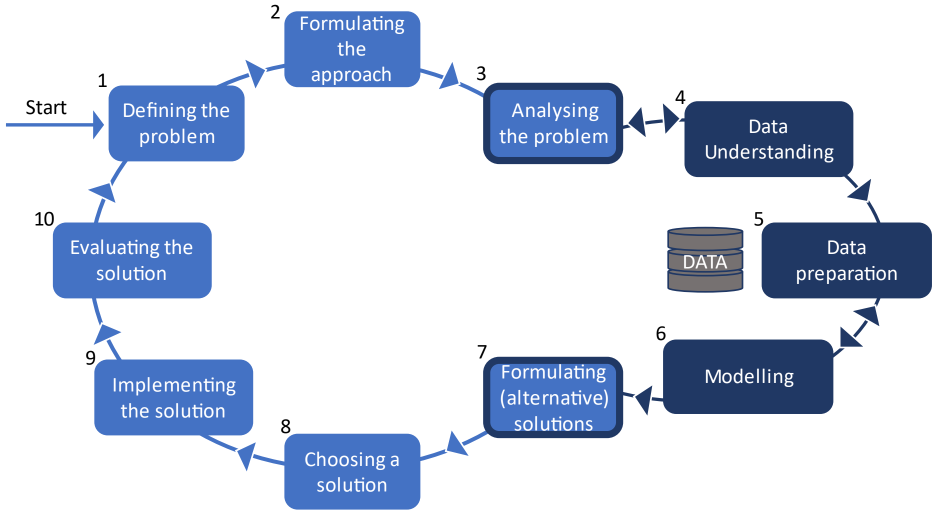


Figure 3: MPSM together with CRISP-DM

Figure 3 shows a combination of both methods. The step of the MPSM between analysing the problem and formulating (an alternative) solution (marked light blue) is extended by a part of the CRISP-DM cycle (marked dark blue). It includes the data understanding, the data preparation, and the modelling, centred around the usage of the record data of ProRail. The cycle starts with defining the problem.

1.4.3 Research design

Next to the core problem, the main research goal and the research approach, research questions are formulated. These questions are based on knowledge and action problems that occur while going through the steps shown in Figure 3.

The research starts at the first phase of defining the problem. The first two phases are discussed in Sections 1.4.1 and 1.4.2 respectively. The information for these phases is gathered from conversations with the supervisors of ProRail. Multiple meetings with the supervisors ensure the understanding and formulation of the problem ProRail faces.

To formulate an approach to get from the reality to the norm, the reality must be defined first. This is done within the phase of analysing the problem, namely analysing what the current state looks like. Also, the current dispatching rules are described (Section 2.1). To get to these answers, the first knowledge question is defined as:

RQ-1: 'To what degree does the current allocation meet the norm?'

The answer to the first research question is defined in Chapter 2, by using the data provided by ProRail. The outputs of the analysis are represented in the four KPIs. Data analyses are needed to get these KPI scores. In combination with the CRISP-DM phase of data preparation, a data validation process is constructed. The data validity includes checking on completeness, defining inclusion and exclusion criteria for the data, and tracing back how the data was put into the system (Section 2.2) When the data analysis is done and the answer to RQ-1 is formulated, the conclusions of the current state on reaching the research goal are drawn.

After the analysis of the current state, the phase of setting up a model starts. There are various types of models to use. What model to pick highly depends on what is provided, the problem, the variables, and the needed solution. To pick a suitable model to apply, the knowledge gap of picking the correct model is filled. A literature research in Chapter 3 filles this gap and a realisation of the model in Chapter 4 answer to the following research question:

RQ-2: 'How can the chosen allocation model best be constructed?'

Three steps are defined to find a suitable model, namely defining what a model is, what the characteristics of a model are and finding theories and examples of models that fit the ProRail case. Based on this theoretical basis in Chapter 3, a model is constructed in Chapter 4 using the programming tool VBA, in combination with Excel. These programs are used to construct the model and analyse the data.

The model is a good tool to analyse runs of the model. However it will only provide outputs for a specific run, depending on the set of chosen variables. ProRail formulated boundaries (Section 5.1) to the possible scenarios (and runs). To know what scenario would be the best one, the model should be run for multiple scenarios. To do this, a framework is constructed in Chapter 5 to structurally analyse all possible scenarios**.** This results in the question:

RQ-3: 'How should a framework for the allocation model be constructed to compare scenarios?'

After the runs of the model for all scenarios are completed, the outputs (KPIs) are analysed. A visualization of the results is made in the phase of choosing/presenting a solution. ProRail requests a visualization to easily understand how results are generated. In general, the dashboard is built up out of two parts. The first part shows the outputs per run of the allocation model, in the before mentioned KPIs. This enables a good comparison between the different configurations of the model. The second part visualizes the actual working of the simulation. For understandability, a visualization shows the steps that the model makes. Section 3.2 explains the appropriate way to do so. The underlying research question is formulated as:

RQ-4: 'How should the results be visualized to form an easy to understand outcome for ProRail?'

Depending on the requirements of ProRail, an appropriate method is chosen. Next, the visualization of the results is built and added to the dashboard as explained in Chapter 6.

After all the results are gathered and a compared in Chapter 7, and conclusion is drawn in Chapter 8. This is part of the phase of (alternative) solution formulation. To bring an advice to ProRail what would be the best allocation to achieve the research goal, the following research question is answered:

RQ-5: 'What is the best allocation method?'

Chapter 9 explains all limitations of the research and their consequences, and future research.

Chapter	1	2	3, 4, 5	6, 7	8, 9
Phase	- Defining the problem - Formulating the approach	- Analysing the problem - Data understanding	- Modelling	- Formulating solutions	- Implementing solution - Evaluating solution - Choosing solution
Steps	- Company description - Defining the core research problem - Research design and research question	- Data exploration/under standing - Data validation - Analysis of the current state	- Comparing and choosing an allocation model - Constructing simulation - Constructing framework	- Formulating the results - Analysing the results - Visualizing the results	- Conclusion to the research Recommendations to ProRail - Limitations of the research
RQs		1	2, 3	4	5

Figure 4: Overview of steps per phase.

Figure 4 provides an overview of all the phases of the research methodology, their steps, the chapters in which it is discussed and the research questions related to them. It serves as a reading guide for the rest of the report.

1.4.4 Validation and verification

To ensure the quality of the research, validation and verification are essential. To verify the research design, two steps are key. The first one is to meet periodically (every week shortly) with the supervisor of ProRail to discuss whether the progress made is still within the agreed terms. The other step is to discuss the progress and choices made with the supervisors of the University of Twente (UT). They have good insight and experiences in research, and can help to overlook the whole process.

To check on internal validity, the constructed allocation model simulates the current allocation. Comparing the KPI scores of the simulation to the KPI scores of the current situation (Section 4.4) gives insights into how the simulation performs. If the results, for both situations expressed in KPIs, are similar it means the simulation can make a close approximation of the actual current allocation. Next, other scenarios can be tested and analysed. If this is not the case, alterations are made to the model where possible.

Another point on internal validity is the quality of the selected data. This quality is guaranteed by selecting the correct data from ProRail. The data provided by ProRail is an exact copy of the incident information entered to the system when the incidents occurred. The timeline selected is a period before the COVID-19 crisis. COVID-19 had a massive influence on the freedom of people and therefore the train services. To get a fair representation of reality, the period of June 2018 until June 2019 is chosen.

Next to internal validity, a look is taken to the extent to which results from the research can be applied to other situations (also called external validity). This is guaranteed by looking at the possible limitations of the research in every step that is conducted. All assumptions are properly explained to provide a complete and coherent advise to ProRail (Chapter 8). In this advice, all limitations are shared (Chapter 9).

1.5 Deliverables

Ddeliverables are defined for ProRail to understand the solution proposed to them by the end of the research. They are based on the steps taken to reach the research goal. The deliverables are: an overview of OCCR ProRail business operations.

- measurements on the current state
- an allocation model
- a framework wherein the allocation model works
- a visualization of the results that is easy to understand
- man advise in relation to the comparison of the current and suggested state

2. Current situation

To analyze the problem that ProRail is facing, research to the current allocation system of ProRail is of essence. Answering RQ-1 ‘To what degree does the current allocation meet the norm?’, gives insights about the current applied system of allocation and the performance of this system. The performance analysis explains the quantifies difference between the norm and reality. In Section 2.1 the current allocations system is discussed, followed by an analysis on this in Sections 2.2, 2.3 and 2.4. In Section 2.5 the chapter is concluded after which the next steps in the research can start.

2.1 Current allocation system

To gain insights into how the current allocation system works, an interview is conducted with one of the ALs at Prorail (appendix D). He has nine years of experience in the job and is currently stationed at the most south ICB-location in Eindhoven. Currently ProRail is using a so called ‘slim allermeren’ or smart-planning tool to allocate their ALs. Before, the incidents were regionally divided. This means that the incidents occurring in a certain region had to be handled by the assigned AL for that region. This had the big disadvantage that incidents located closer to an AL of another region were still assigned to the AL of the region. Another disadvantage is the occupation of the colleague AL in that region. The work shifts were divided in such a way that when one AL worked on the day shift, the other AL worked the night shift. However, the off-duty colleague also served as backup in extreme cases of many incidents. After the colleague stepped in as backup, a day shift was still ahead of them, resulting in long working days. Currently the contract agreements have changed so that such situations cannot occur anymore, therefore protecting the employee against overworking.

The contractual change and the significant disadvantages that the old allocation system has, needed to be solved by creating a new allocation system, named ‘slim allermeren’ (SA). It eliminated the boundaries of allocation per region. When an incident occurs, the closest available AL is assigned, depending on the type of incident and what exactly is needed. The ALs at service are coupled to a car that tells the AL exactly where to go. This enables fast transportation and fast and flexible manner acting ALs. Before the ‘slim allermeren’ system, ALs communicated with each other a lot to tailor the old system making it more workable. With the new system, the contact is mainly between the AL and the OVD-I. The centralized contact helps the overall coordination.

The dispatching rules SA uses are simple. It allocates the closest AL available to the incident. An AL is available when he/she is not traveling to/back from or working on an incident. The unstructured rescheduling and unplanned allocation following from the contact between the OVD-I and the AL are not included, as this is also not a structural part of the SA.

While the SA system is a good step towards better allocation of ALs, the system can still be improved a lot by taking over some of the decisions the ALs and OVD-Is have to take now.
As stated, the SA system is mainly used by the OVD-Is and ALs. It forms the core of the AL allocation, so ALs can do their work and handle incidents efficiently and effectively. The OVD-Is also have insights into SA, in combination with the overall allocation throughout the Netherlands. This gives them a good position to step in and contact ALs where needed and answer all the questions an AL may have.

Spoorweb, the administrative tool ProRail uses to report all incidents and their progress, is not part of SA, or vice versa. The SA uses the information of Spoorweb and sets out actions for chosen ALs to do. Spoorweb and the OVD-I’s remain the primary information sources.

The stationary locations of the ALs play a crucial role to get to an incident timely. The total number of allocated ALs to a stationary locations has influence on the coverage rate of the mount of incident the location can handle. Currently there is always one AL assigned to work at one stationary location.

City	Coordinates	Number of Als
Eindhoven	X: 5.2124058 Y: 51.7579386	1
Rotterdam	X: 4.5158209 Y: 51.869963	1
Rotterdam Harbor	X: 3.1240703 Y: 51.8464202	1
Schiphol	X: 4.7546239 Y: 52.3062972	1
Utrecht	X: 5.0760149 Y: 52.1031976	1
Zwolle	X: 6.0744135 Y: 52.5033179	1

Table 1: Current ICB locations of ProRail

The locations in Table 1 are logically chosen by ProRail to have fairly good coverage over the Netherlands. Most of the ALs are located in the west of the Netherlands since most of the incidents occur here. The locations of Zwolle and Eindhoven are more remotely located. They have a bigger area to cover. For the location in Eindhoven, the region of Limburg, parts of Zeeland and Gelderland need to be covered as well. The stationary location in Zwolle covers the North of the Netherlands, namely Groningen, Drenthe and Friesland. The interviewed AL pointed out that there is uncertainty among employees if these areas are properly covered and if actions should be taken. This underlines the importance of this research to analyze the current allocation and draw conclusions about the influence of reallocation. Chapter 8 will go into dept more on this.

When there is no incident to handle, the ALs are at the stationary location or somewhere around the stationary location. From the interview with the AL a radius of a maximum of 30 minutes driving is taken as the circle around the stationary location where the AL would be. In general, it can be assumed that the AL is on average located at the stationary location.

2.2 Analysis approach

To analyze the current situation, the KPIs of average travel time, the proportion of times the travel time is larger than 45 minutes, the utilization of the ALs are explored and the number of times there are not enough ALs available. To get to these numbers, an approach of analysis is needed. First, the data received by ProRail is filtered and metadata is created. The data lists gathered by ProRail is an overview of the Spoorweb information for every incident that occurred during a certain period of time. The data is fairly extensive, with 88 characteristics per incident. Not all of this information is needed for the analysis, but only a small part as the phase of data preparation of the CRISP-DM implicates. Table 2 shows all chosen characteristics, with an explanation and motivation for each of them.

Characteristic	**Definition**	**Motivation**
Incident number	Every incident has a unique incident identifier.	To ensure an incident is not double in the data, the incident number is included
TIS score	TIS is short for Train Incident Scenarios. It indicates what kind of incident happened on the track.	Only for a Tis score of 1.2 and higher an AL has to step in. This is an important criterion to select.
Latitude	The angular distance of a place north or south of the earth's equator.	Important to determine the travel distance for the AL
Longitude	The angular distance of a place east or west of the Greenwich meridian.	Important to determine the travel distance for the AL
Assigned AL	The assigned region the AL comes from.	To know which AL is assigned, and in combination with the coordinates, the travel distance can be determined.
Time start incident	The time and date that the incident occurs	To determine the duration of the incident, and so the time the AL has to spend at the place of incident.

Time end incident	The time and date when the incident is solved	To determine the duration of the incident, and so the time the AL has to spend at the place of incident.

Table 2: Incident characteristics

As timeline 13 months of data is chosen from 31-05-2018 to 30-06-2019. This data is recorded before COVID-19 hit the Netherlands. Corona had big influence on the freedom of people, and therefore the ability to travel. To get a good glance of the current situation, without corona, the data before the corona crisis is used. During the abovementioned period 21844 incidents occurred.

Out of these 21844 datapoints (incidents), only a certain incidents request the attendance of an AL. As stated in Table 2, an incident with TIS score of 1.2 and higher applies for the help of an AL. TIS strands for 'trein inincident scenario's', or train incident scenarios. It differentiates 5 types of incidents with each 4 sub ratings (ProRail, 2021). By first sorting on the TIS score, all the relevant incidents are selected. This reduces the dataset to 4537 rows.

The difference between the start and end moment of the incident is used as the indication of duration of the incident. When an incident occurs and an AL is needed, an AL will be sent. This means that the travel time to the place of incident is included in the time difference between the start and the end of the incident. Since the data of the travel time of ALs is not recorded by ProRail, it is out of the scope of this research to determine the exact time the AL worked on the incident. Taking the estimated time that will follow from the estimated incident time will be too inaccurate, because many unstructured changes are made to the allocation, as indicated in the interview with the AL. Also, the ALs are not always exclusively located at the stationary location when they are unoccupied, as is stated as well in the interview. This brings lots of uncertainties.
Therefore it is chosen to include the original travel time to the duration of the incident. This means that the duration of the incident will be longer than it actually is. Where this brings invalid results in terms of duration of incidents, it doesn't from a problem in relative perspective. The purpose of research is to look how reallocation can have a (positive) influence to ProRail. This means that if the same method of deriving the travel times and incident duration for the simulations are used, the comparison in KPI outcomes is still valid. Therefore, for the purpose of this research, the reality can be determined by the above mentioned method, by adding the travel time twice (to go to the incident and back) to the incident duration. This is also in line with the currently used 'slim alloceren' because this system uses a similar approach to determine if an AL is available or not.
Also, from the interview with the AL it turned out that after a maximum of five hours working at a certain incident, an additional AL will be sent to take over the tasks. This means that the duration of the incident has a max of five hours.

After the duration of the incidents is calculated, the coordinates are determined. This part splits up in two parts, the coordinate alteration of the incidents and the coordinate generation of the ALs. The simulation is constructed in such a way so that it calculates distances using a grid format. Ideally the coordinates would be used instead of transforming the coordinates into a grid format. However during construction of the simulation, a grid is used to calculate the coordinates. In the end of the research it didn't turn out to be necessary to use such a grid in the simulation. To make a fair comparison to the outcomes of the simulation, a grid is used in the analyses of the current situation as well.
To use the coordinates within this format, all the coordinates are translated into this roster. The coordinates of the incidents are given in the standard format, namely latitude and longitude. To convert these into the roster the simulation uses, the dimensions of the roster format and representing area (the Netherlands) are needed. The roster is 32 blocks on the horizontal axis and 38 blocks on the vertical axis. Measuring between the most outer points of the Netherlands, using Google maps (Google., 2022), the Netherlands ranges from 3.3571 to 7.2275 degrees on the horizontal axis (longitude) and from 50.7506 to 53.5559 degrees on the vertical axis (latitude). (The Netherlands is considered fairy small, so the assumption is made that the curve of the earth does not have influence.) To determine the locations in the grid of the incident locations, the following formula is used:

$$X_{coordinategrid} = \frac{(X_{coordinate} - X_{start})}{3.8704} * W_{grid}$$

$$Y_{coordinategrid} = \frac{(Y_{coordinate} - Y_{start})}{2.8053} * L_{grid}$$

The Latitude and Longitude are the locations of the incidents given by ProRail. Xstart and Ystart are the lowest horizontal and vertical values, 3.3571 and 50.7506 respectively. Lgrid and Hgrid are the Width and Length of the Grid, 32 and 38 respectively. The formulas are divided by the longitude/latitude distance of the Netherland in degrees (3.8704 and 2.8053 respectively). These formulas convert the locations of all incidents. In some cases, coordinates of the incident are not included in the data. When this is the case, they cannot be used and will therefore be deleted out of the incident log. The second step is to determine the locations of the ALs. Table 2 shows the locations of the current stationary locations of the ALs. By using the formulas above, the locations can be converted into the roster format.

After determining the all the needed locations, the distances between the AL stationary locations and the incident locations can be determined. This is done by:

$$D = \sqrt[2]{\left|X_{coordinategrid_{AL}} - X_{coordinategrid_{incident}}\right|^2 + \left|Y_{coordinategrid_{AL}} - Y_{coordinategrid_{incident}}\right|^2}$$

D (distance) is measured by the straight line from the AL location to the place of incident. To determine the travel time, multiplying the D by the travel time per grid-unit will give an unrealistic estimate. To determine a ratio between the length of an diagonal line between two locations and the actual distance of the route, a random sample (n=20) of incidents is taken. For each of these samples, the actual travel time between the two locations is determined using Google Maps (Google, 2022). Next, a ratio between the estimated, diagonal distance and the actual travel time can be found for each of the 20 incidents. Putting the results of the ratios into a box plot gives Figure 5 as result.

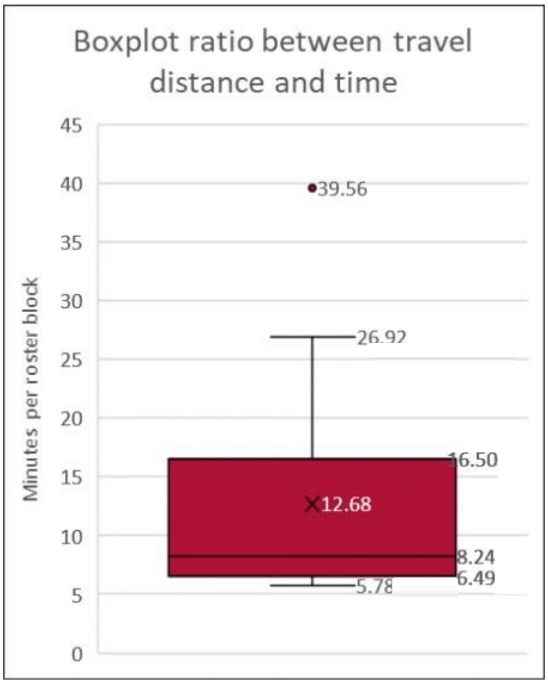


Figure 5: Boxplot for the travel time ratio between distance and time

The average ratio is 12.69 and will be multiplied to the estimated distance for each of the selected incidents. This gives the travel time estimate. The boxplot shows some pretty large outliers. In further research a method to divide the travel times into categories with each a suitable ratio will increase the accuracy of the travel time estimations. Together with the duration of the work on the incidents, the KPIs can be determined.

2.3 KPI Calculation

To analyze the current situation, values for each of the 4 KPIs are calculated. First is the KPI that measures the average utilization of the ALs. The formula for this KPI is (PorteBrown, 2022):

$$Utilization = \frac{\sum_{a=1}^{numberAL}\left(\sum_{i=1}^{n}\left(2 * T_{travel,i,a} + T_{incident,i,a}\right)\right)}{T_{total} * amountAL}$$

To know the average utilization of the ALs, the total time spent on activities to solve incidents is calculated. By summing twice the travel time (to go to the incident and back) and the duration of the activities at the place of incident, the timespan of one incident is calculated. Adding this number for all incidents (a 'n' number) and all ALs gives the total time spend. To get average utilization per AL, the number is divided by total number of time that has passed (in minutes), times the number of ALs (number ALs) that were at. In the calculation, the difference between day and night is not considered. To get a fair comparison to the outcomes of the simulation, the simulation has to evaluate for the whole day as well. The T_{total} therefore is 13 months * 31 days * 24 hours * 60 minutes = 580.320 minutes, and the number of ALs (numberAL) is 6.

The second KPI to analyze is the average travel time. This will be done using the following formula:

$$Average\ traveltime = \frac{\sum_{a=1}^{numberAL}\left(\sum_{i=1}^{n}\left(T_{travel,i,a}\right)\right)}{n * numberAL}$$

The total travel time is determined by adding all travel times (a 'n' number of incident) for all ALs (numberALs) and dividing this by numberAL and the number of incidents.

The third KPI of number of times (N) the travel time is larger than 45 minutes and is determined by:

$$\begin{cases} \text{If } T_{travel,i,a} > 45 & \text{then} \quad n=1 \\ \text{If } T_{travel,i,a} < 45 & \text{then} \quad n=0 \\ N=N+n \end{cases}$$

The fourth KPI, the number of times (M) there are not enough ALs available, is calculated in the same way as the third KPI. It is determined by:

$$\begin{cases} \text{If NumberAvailableAL} = 0 & \text{then} \quad n=1 \\ \text{If NumberAvailableAL} > 0 & \text{then} \quad n=0 \\ M=M+n \end{cases}$$

2.4 Results

After defining the formulas to calculate the KPIs, the values are calculated for the current allocation using the data from ProRail.

To calculate the utilization and the average travel time, the number of ALs (numberAL) is not necessary to use for the analysis of the current situation, since all incident are listed in the datasheet independent from the AL that helped them. This means the summation sign is not needed there. Therefore the numberAL has the value 1. Filling in the rest of the formula gives a utilization of 27.9%.

For the average travel time a boxplot is created in Figure 6. It indicates that there are some substantial outliers. It also shows that the Average travel time (similarly calculated as the formula above) is estimated at 51.8 minutes, nearly 7 minutes above the threshold.

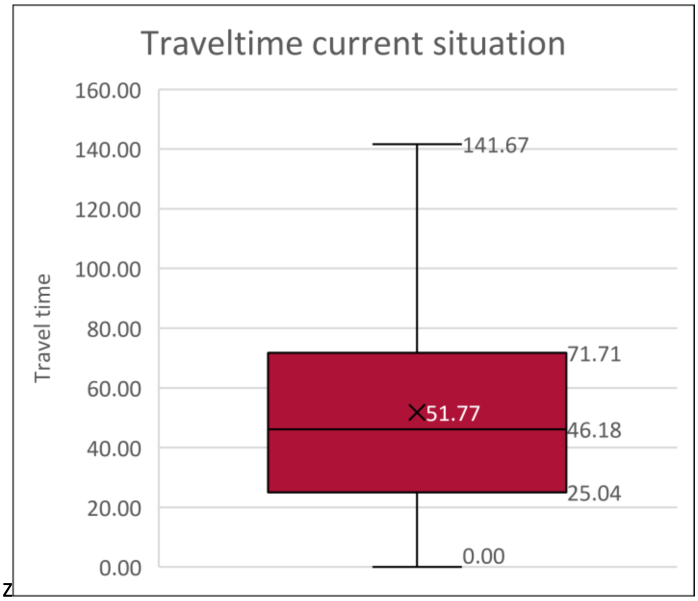


Figure 6: Boxplot of the travel time for the current situation

The Third KPI indicates the number of times the 45 minute travel time limit was not met. Going over all the selected data and their corresponding travel times, the 45 minute goal was not met for 2398 incidents, or 52.9% of the times.

The fourth KPI can't be determined based on the provided data of ProRail. Spoorweb does not include data to determine the number of available ALs (NumberAvailableAL). This KPI can only be determined by simulation.

2.5 Conclusion

It can be concluded that the norm is not met in the current situation. With an average travel time above the 45 minutes and more than half of the incidents having a travel time of over 45 minutes, the current situation needs improvement. In its current state, ProRail is not reaching its goal of travel times below 45 minutes for 95% of the incidents. The relatively low utilization can be caused by including all minutes of 13 months instead of only the times trains drive or ALs mostly do their work. On the other side, as stated, additional time is included in the duration of the incidents. Also as indicated, for all incidents the same ratio is used. This can potentially cause incorrect values. As these insights are out of the scope of this research to determine, there will be assumed that the KPIs are correctly determined given the assumptions.

3. Literature review
This chapter describes a literature research to partially answer research questions 2 and 3. To get from defining the problem to answering the main research question, the knowledge gap must be filled. This chapter goes into the theoretical depth on the topics of modelling in Section 3.1 and visualization in Section 3.2. The chapter is concluded with a conceptual framework in Section 3.3.

3.1 Modelling
Models are known in a wide variety of ways and applications. This part of the literature studies is dedicated to structurally find an appropriate allocation model. First, models and their characteristics are defined. Based on these definitions, a search towards theories and examples of applicable methods is conducted.

3.1.1 Definition of models and simulations
Allocation problems involve the distribution of resources among alternatives in order to minimize or maximize the wanted outcome (operations research - Resource allocation, 2022). To do so, a model can be used. A (mathematical) model is defined as a representation of an actual situation that is used for better decision-making and simplification of the actual situation (Winston, W. L., 2022). It helps to predict the effects of changes to the system (Modelling & Simulation Tutorial, 2006).

It does so by seeking values for the decision variables that optimize an objective function, while satisfying the given constraints (Salazar, R.,2021). An objective function is a (mathematical) equation with the wish to be maximized or minimized (Winston, W. L., 2022). In case of the re-allocation for ProRail, the function is based on the problem statement. The objective function can be formulated as 'minimizing the average travel time of the AL' and 'minimizing the number of times the norm T<45 is not reached'. The objective function however must take into account some constraints. They restrict the values of the decision variables (an unknown in an optimalization problem).

Analytical models or simulations can help to formulate a solution to a model, taking constraints into account. These exist in a wide variety, all with their own purposes. A simulation is a type of application to solve a model. In 1990 Humphreys presented a definition for simulations: "A computer simulation is any computer-implemented method for exploring the properties of mathematical models where analytic methods are unavailable" (Durán, J. M., 2020). Hartmann went a step further in his definition and stated: "scientists reserve the term 'simulation' exclusively for the exploration of dynamic models" (Hartmann, 1996). From these two statements, a simulation will be defined as:

- A simulation imitates another process
- A simulation is the result of solving the equation of a dynamic model
- A computer simulation is the result of having a simulation run on a physical computer

As with models, simulations also exist in many ways. Section 3.1.3 go into more depth on this. To the basis of simulating, simulations follow a basic structure as showed in Figure 7.

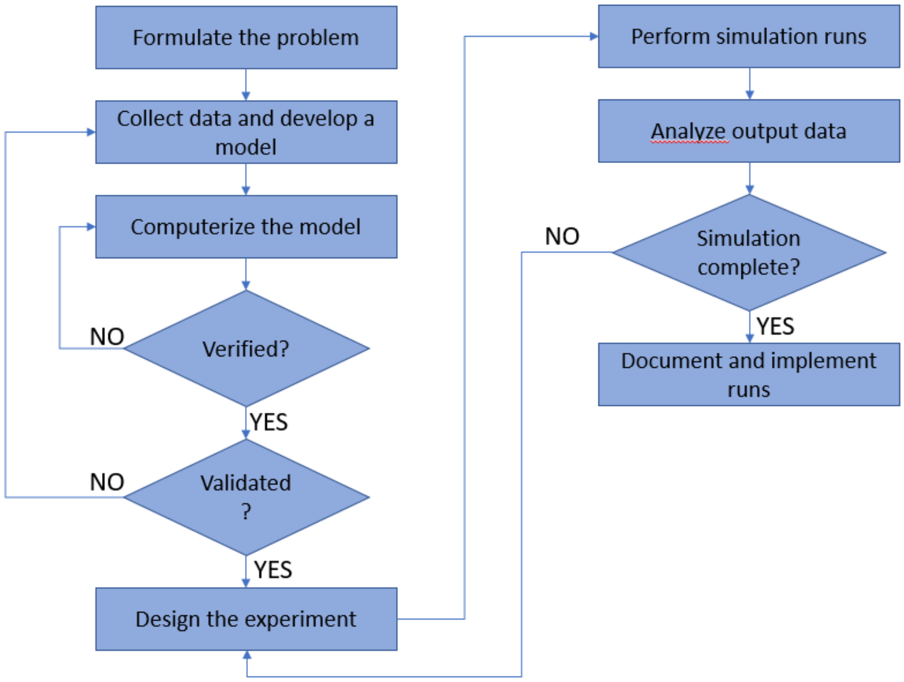


Figure 7: Steps in simulation study (Winston, W. L., 2022)

The first step is formulating the problem to understand for what the simulation is built and what the final purpose is. After the problem is formulated, appropriate data is collected, and a suitable modelling technique can be chosen. After gathering the data and formulating the model design, the simulation can be computerized.

Once the simulation has been verified and validated, the design of the experiment can start. The different situation configurations are formulated by changing the chosen decision variables to values suitable for each situation. After the design of the experiment has been established, the different simulations can be run. This gives a specific output for every situation. To get to a conclusion, the results will have to be analyzed. This can be done with charts and graphs, statistical measures, sensitivity analysis and parametrized simulation (Simulation Tutorial - Analysis of Results., 2012).

3.1.2 Characteristics of models

Each model has their own characteristics. To find the right model, the distinction is made between discrete/static and continuous/dynamic models (Winston, W. L., 2022)). To understand the difference better, the definition of continuous and discrete is explained by comparing continuous and discrete variables. An example of a discrete variable is the number of people in a room at a certain moment. Only an integer number of people can be present in a room. However, variables like temperature cannot be counted. There are uncountable points in an interval. This means that temperature is a continuous variable.

Similar to discrete variables, static models are a representation of a system at a particular point in time. They are based on variables that change at a countable number of points in time. Dynamic models on the contrary, like continuous variables, have uncountable points within an interval. Dynamic models evolve over time. They are based on variables that change in a continuous way, and do not change suddenly between timepoints. Instead, there are an infinite number of 'timepoints'. This means the model goes continuously over time. The type of dynamic model depends on the degree of random variables. Deterministic models have no random variables, where stochastic models have one or more random variables.

Characteristic	Choice	Reasoning
Static, dynamic	Dynamic	The data used changes over time and is not usable when only one of many timepoints is used/analysed.
(In case of a dynamic model) Stochastic, deterministic	Deterministic	Record data is used, also called back testing (Back testing Definition, 2021). This data is gathered from incidents that already took place. This means the ProRail case can be approached myopic in comparison to the real life (stochastic) situation.

Table 3: Characteristics table ProRail case.

After classifying the characteristics of a model, the appropriate characteristics for the ProRail AL allocation problem are chosen. Table 3 shows the choice for each of the two characteristic with the reasoning behind it.

3.1.3 Establishing the allocation method

Now that the characteristics of the model have been determined, the actual approach towards solving the model can be found. The goal of the research of J.L. Vile et al. (2016) on the time-dependent scheduling of emergency medical services is similar to the ProRail case. The utilization of the resources should be maximized to minimize the costs or, in the case of ProRail, the travel time. In the research of J.L. Vile the demand is unknown, and so a demand forecast has been applied. When only the probabilities of occurrence of incidents are known, stochastic models like a two-stage stochastic programming (Leo, E., Et. Al., 2018) would be applicable.

However, data is provided by ProRail to enable the possibilities for deterministic modelling.
In the study of J. Catumba-Ruiz et al. (2020), a hybrid optimization method for reallocation of mobile resources has been constructed. Here, the allocation of emergency services is determined, depending on the place of incidents, travel times and ambulance assignment. The case is fairly similar to the ProRail case, where the incident handling performance depend on the allocation of the ALs. As the travel times are also one of the key outputs of the model, the case can be used as an example to base the model on. J. Catumba-Ruiz et al. use a discrete event simulation (DES) to simulate a simplified version of the incident reporting, ambulance assignment, ambulance movement and attention process. Discrete events occur on specific points in the simulation, for which the DES marks the changes the discrete event causes.

Another approach that gives similar output is the continuous simulation. A continuous simulation continuously checks the system response. When an event occurs, the system adapts while it is running throughout the duration of the simulation (Howard, E., 2020). For the ProRail case, the simulation should run over time per minute, indicating the incidents that will take place according to the data. In this way all timepoints are simulated. Therefore, the continuous simulation is more suitable.

The continuous simulation gives outputs for a specific combination of AL locations and number of ALs at these locations. To answer the research question with the goal of increasing the utilization and lowering the travel times of the ALs, multiple allocation possibilities will have to be compared. With only one simulation, an optimal solution cannot be found. This means that the continuous simulation has to be used as a tool in a framework to compare the different simulations (Leo, E., & Engell, S., 2018). With a local search, a simulation of the current allocation is generated and an algorithm moves from this configuration to a neighbourhood configuration in the search space, until a (good) solution has been found or all the resources are used (Michel, L., et al., 1999). However, as described in Section 1.3.3, there is only a limited option set available to change the current allocation. This means that all possible configurations of the simulation, by varying the number of ALs at certain locations, cannot change a lot from the current allocation. Shortly, the search space is small enough to fully explore (also called complete enumeration). After the static space of scenarios is determined and simulated, the results can be gathered and conclusions can be drawn what allocation configuration would be best.

Using coordinates as the measurement for locations can results in an enormous number of places for possible new stationary location. Simulating all these locations can bring complexity with it. To overcome this, Dearling used a block distance model (Farahani, Z. R., et al., 2011). It has the purpose of generalizing distances in fixed orientations. This means that the coordinates are divided into blocks, each with a fixed unit length. Now the map is divided into squares, all containing a certain number of incidents at a certain time. The block distance model simplifies the location possibilities, but loses accuracy (depending on the size of the blocks).

3.2 Visualization

In the article of K.W.Brodlie (2004) on distributed and collaborative visualization, some requirements are formulated as a minimum threshold. The visualization should be accessible for different stakeholders, each with their own expertise towards the theoretical part. The target users with their main requirements can be formulated as:

- Visualization programmer. The visualization must be flexible enough to show everything wanted in sake of the research, without compromising too much towards understandability. The simpler a visualization is, often the less detail the system can incorporate. Therefore, the number of details included has to be thought over well.
- Visualization end user. Though they are not expert users, they highly benefit from the tailored visualization. This means that details can be incorporated on topics stakeholders know much about. In this way there is a good compromise between the visualization programmer and the end user.

To determine suitable visualization methods based on the requirements, examples of visualization in other studies are discussed. The first suitable example of visualization is given by the research of Thomas Alves on a virtual honeybee colony(Alves, T., et al., 2019). The study simulates the natural intuitive interactions of bees by a 3D simulation, created in Unity3D. It shows a very easy to understand way of visualizing a more complex mathematical model of the interaction between the bees.

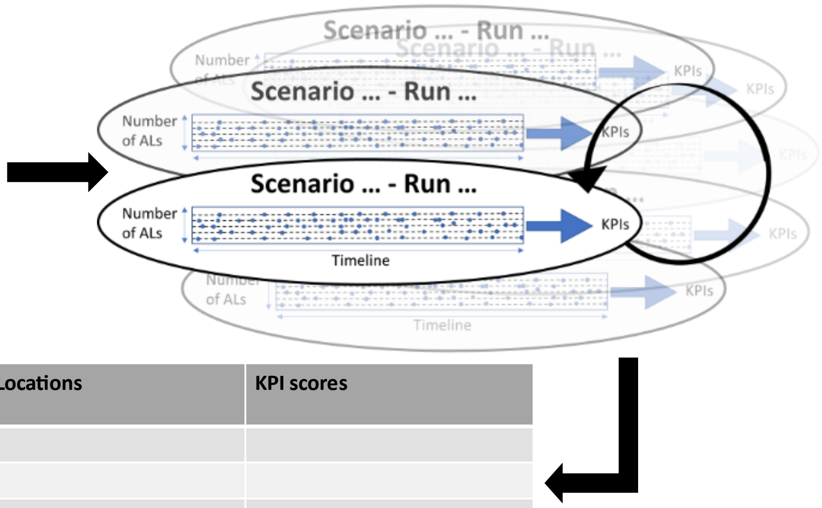
Another example is given by the research on the visualization of parallel branch-and-bound methods, by Yury Evtushenko et. al. Their need of a graphical front-end is formulated as: 'The graphical front-end is aimed at user-friendly graphical visualization and performance analysis of traces produced by either simulator or the real solver.' (Evtushenko, Y., et al., 2016). They do this by showing graphs that change over time when the visualization starts.

3.3 Conceptual framework

Figure 6 shows the conceptual framework. It links the concepts introduced so far and the interrelationships between them.

Scenario	Run	Amount of Als	New locations
1	1	5	0
1	2	5	0
1	3	5	0
…	…	…	…

The static space



Scenario	Run	Amount of Als	New locations	Locations	KPI scores

The KPI outputs of the static space

Figure 8: Conceptual framework

Based on the research goal and the difference between the norm and reality, the outputs are determined in Chapter 1, together with the inputs and variables. Every run has a unique combination of variables. To gather KPI results from the run, a continuous simulation is chosen as it is suitable for the ProRail case (explained in Section 3.1.2 and Section.3.1.3). In Figure 8, the continuous simulation is visualized in the oval shapes. An incident is a dot in the graph, based on when the incident occurred (Timeline) and to which AL it is allocated (Number of ALs). The graph shows how the incidents are allocated based on the number of ALs and their stationary locations.

To make comparisons between runs, a static space is formulated. Because there is a restricted number of possible runs, a local search is not needed. Based on the number of ALs and the addition of a new location, the runs are separated into scenarios. For example, with 7 ALs and no new stationary location, there is 1 AL more in comparison to the current situation. The extra AL can be allocated to one of the current stationary locations. There are 6 stationary locations, which means the simulations should be run 6 times. In case of 8 ALs and no new stationary location, there are 36 possibilities to run the simulation. If these two situations would be the static space, there would be 42 simulations (runs) in total. These 42 runs can be divided into two scenarios, depending on the number of ALs. After defining all scenarios and runs, each scenario is run.
To compare the different runs within scenarios, KPIs values are determined for every run. These are put in the table of 'The KPI output of the static space'. After running all scenarios, the KPI scores can be compared to analyse what would be the best recommendation to ProRail to reach the norm.

To make the outcomes of the simulations understandable, a visualization is created to show how the simulation allocates AL. Also the KPI values will be displayed.

4. Simulation allocation tool (SAT)

In this chapter, the allocation model is constructed to answer the research question (together with Section 3.1.3) ‘How can the chosen allocation model best be constructed?’. First boundary conditions to the allocation tool are set. Section 4.1 will go into detail on the assumptions made to construct the allocation tool and Section 4.2 will elaborate on the data preparation. Section 4.3 will elaborate on the construction of the tool. To validate the simulation, the performance is compared to the current situation in Section 4.4. After the tool is validated, the limitations are discussed in Section 4.5, followed by the conclusion.

4.1 Assumptions

To build a continuous simulation according to the literature research described in Section 3.1.3, assumptions are made. The simulations aims to reproduce the allocation behaviour ProRail used to cover the incidents. However, for most incidents, it highly depends on the case what exactly is needed to so solve the incident. Therefore, a lot of ad hoc measures are taken. To incorporate uncertainties of the work of ALs, like human behaviour and unforeseen interruptive events, assumptions are made. These assumptions are the boundaries in where the SAT has to work.

At first, it is assumed that multiple events will never take place on the exact same time (in minutes). The simulation can either run over all the incidents for every simulated timepoint to see if there is a match, or the simulation can move on to the next incident after one has occurred. The second option saves a lot of computational time. The downside is that it cannot consider, in its basic form, multiple incidents that happen at the same minute. From conversations with the supervisor at ProRail and data analysis, it can be assumed that it won’t happen.

The second assumption states that all months contain 31 days. The analysis on the current situation for the utilization of the ALs assumes that each month has 31 days. If an AL is not allocated to an incident for a whole day, that day should be included to the calculate the utilization. So, to make a fair comparison to the current situation, the duration of one month is always 31 days.

The same principle holds for the fourth assumption. All hours of the day (so 24 hours), ALs are assumed to be ready to work. Because the ALs have day and night shifts, there is always someone ready to pick up the work when an incident has been reported.

Fifth, the travel times are calculated based on the same approach used in the current situation (Chapter 2). Also the durations of the incidents, or worktimes of the ALs, are the same as the ones used in the current situation. Section 2.2 elaborately explains the uncertainties that come with this approach. To get a fair comparison, the same calculation methods are used both for the analysis of the current situation as well as for the SAT.

The sixth assumption is based on the productivity of the ALs. In the simulation the assumption is made that all ALs do their job the same and are all as efficient and effective in doing their job as other ALs.

The last assumption is made based on the ‘smart allocation’ tool ProRail is currently using. The simulation only reproduces the allocation of ALs similar to the method the tool uses. This means that reallocation due to contact between the ALs and OVD-Is is not included in the simulation. Section 4.3 will go into dept how this will work for the construction of the SAT.

4.2 Data preparation

To build the SAT, data from ProRail is needed. However this data is not ready to be used as input for the SAT. This means that data preparation is needed. The first step is to alter the data to the needed form and create meta-data, similar to the process explained in Section 2.2. The dataset created therefore is exactly the same, which ensures a valid comparison.

All start times of the incidents are rounded up per five minutes. For example the date ‘19-7-2018 15:42:58’ becomes ‘19-7-2018 15:45:00’. This change is made to decrease the computational time. As explained in Section 4.3, the simulation loops over time to allocate an AL to an incident when the incident meets the timepoint of the loop. (This is according to the principle of a continuous simulation as described in Section 3.1.3) Looping per five minutes instead of looping per second reduces the loop by a factor ((60/5)*60 =) 720. This is a significant decrease in the needed computational power and so the time the simulation takes. A side effect to this change is the possibility of having the same dates and times occurring in the dataset. The assumption in Section 4.1 states that the SAT is not able to process that. Therefore five minutes are subtracted from the start time. Based on the fact that the incidents occur fairly random and the duration of the incident is calculated before the changes to 'per five minutes' are made, this change is assumed valid to make. Running the SAT per second would be ideal, but this change makes it easier to operate the SAT

Sometimes it appears that the data is incorrectly ordered on date. This means the incident that occurs later than the incident before is listed in the wrong orientation in de data sheet. By the way the SAT is constructed it won't be able to handle this mistake. Therefore these datapoints are switched around so that the start times of the incidents are in a chronological orientation.

Another change made is the correction of the orientation of days and months. When selecting and processing the data, the format of the days and months sometimes changes for unknown reasons. Therefore a loop goes over the incidents to check this and fixes it when needed.

It can be the case that, despite the efforts to correct the data where needed, there are still errors in the data. The orientation of dates, the correct format of the cells or invalid primary data can be some of the causes. To overcome this, manual changes can be made to the data. In most cases it is easy to recognize what is wrong with the data points when compared other datapoints. Because the selected data is quite extensive, a tool is constructed to see if all the datapoints are correct. In Section 6.1, the function 'Looping check' is explained. For example, it could be the case that a date doesn't match this format. This means the SAT will stop at that certain incident with its check. The row number of the incident is indicated and the selected data can be checked for mistakes.

The correction tool and the automatic changes made will also offer a good solution in most cases.

4.3 Construction of simulation

After the assumptions are made and the data is selected and corrected on mistakes, the SAT tool is constructed. To do this, it is important to take a good look at the dispatching rules the SA uses, as the SAT simulates the behavior of this tool. As Section 2.1 states: '*The dispatching rules SA uses are simple. It allocates the closest AL available to the incident. An AL is available when he/she is not traveling to/back from or working on an incident. The unstructured rescheduling and unplanned allocation following from the contact between the OVD-I and the AL are not included, as this is also not a structural part of the SA*.'

Next the dispatching rules are translated to code to use in simulation. Figure 9 displays a simplified version of the simulation, explained in pseudocode. All the main components are included, beginning with the input of the simulation, followed up by the process, resulting in the output generated.

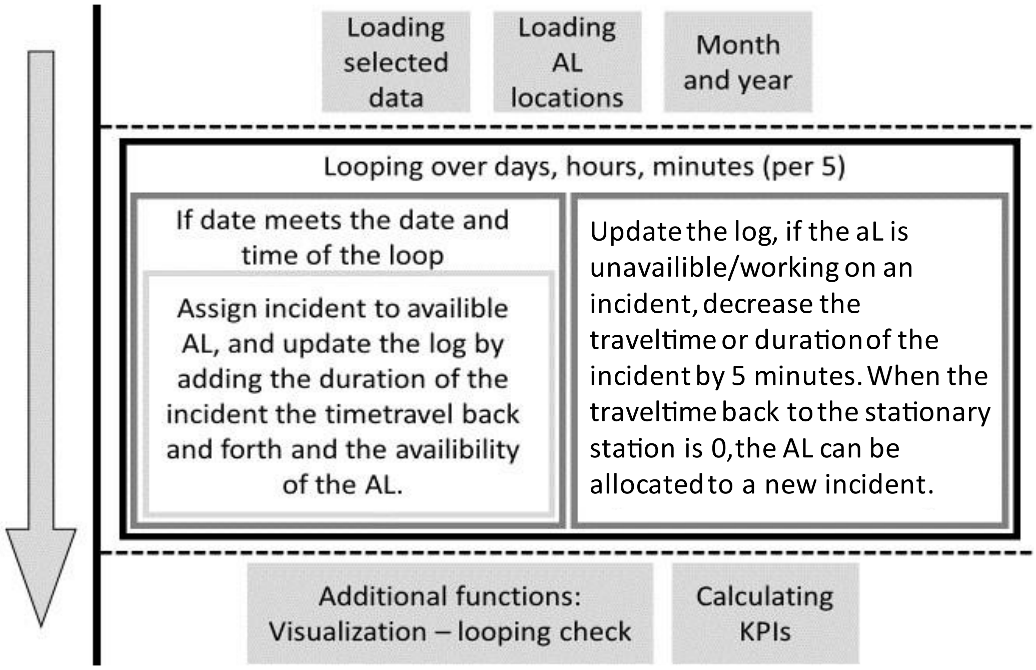


Figure 9: Simplified representation of the simulation code in pseudocode.

The first step is to load the correct information into the SAT. This includes the selected data as Section 4.2 describes, the ALs and their selected locations, and the month and year the simulation will run over. After all the data is loaded, the SAT starts running over time. The simulation runs for 13 times a month of 31 days, over 24 hours, every five minutes. Running the SAT per month instead of per year decreases the number of calculations dramatically and allowed quicker development of the SAT.

When an incident occurs in the data, the closest available AL (given the number of ALs and their corresponding stationary locations) is selected, just like the SA does. When all ALs are occupied, the SAT increases the number of 'maximum capacity' by one. If this is the case, the incident for which the maximum capacity is reached will be allocated to the latest assigned AL. This means the AL won't finish the incident and will go right away to the other incident. In reality ProRail fixes this by allocating an temporarily extra AL on the remaining incident. However this situation is unwanted wherefore the number of 'maximum capacity' should be as low as possible. In Section 4.5, a recommendation is made how to handle this better.

After the AL to allocate is determined, a log is updated. This log stores all information of the incidents (incident number, x coordinate, y coordinate, travel time, incident duration and assigned AL) and the information of the ALs. In this log, every AL has four characteristics; the availability, the travel time to go to the incident, the duration of the incident and the time to travel back to the stationary location (same as the other travel time). When an AL is assigned to an incident, its availability changes and the incident duration and travel times are updated in the log.

The log is updated every time the SAT continues to the next 5 minutes. This can either mean that the above explained process of assigning an AL takes place, nothing changes or the runtime of the incident can decrease. In the latter, the SAT checks if an AL is available or not. If the AL is unavailable, it will decrease the travel time to the incident, the worktime, or the travel time back by 5 minutes. First the travel time to the incident will decreased by 5 minutes every cycle until its value is zero. Then the same happens for the incident duration, followed up by the travel time to go back to the stationary position. If the AL is back at is stationary position, the availability is updated.

When all the (13*31*24*12 =) 116064 cycles are run, the last phase of figure 9 starts. If the dashboard settings allow the visualization to run for a certain month and day during a specific time interval, it visualizes the data in the log by coloring parts of the map of the Netherlands (Section 6.2 provides more information). If the option for looping check is turned on, all incidents simulated are checked on their format.

The SAT returns KPI values, meant to indicate the performance of the simulation run. It will output the utilization of each AL, the average travel time, the number of times the travel time is larger than 45 minutes, the largest and smallest travel time and the number of times no ALs were available (maximum capacity). The KPIs of the average travel time and the number of times the travel time is larger than 45 minutes are calculated based on the log. The utilization of each AL is determined by counting the number of times (in a month) the AL is unavailable (travelling or solving an incident). By dividing this number by the total number of timesteps per month in the loop (8929), the utilization per month of each AL is calculated. To get the overall utilization of ALs per run, the average utilization of an AL per 13 months is calculated first. Next the average utilization across the ALs is calculated.

4.4 Validation of the simulation tool

After the simulation is constructed, the validation process of the simulation starts. This is done by comparing the KPI outcomes of the current situation to the KPI outcomes of the simulation when the same locations and selected data are put in. To do this, the simulation tool runs for 13 months, June 2018 until June 2019. Table 4 displays the output of both situations and the difference between them. The KPI of 'Times not enough ALs available' cannot be calculated, as Section 2.4 states. Therefore this KPI is left out of comparison

KPI	Current situation	Simulation	Difference
T > 45 minutes	2398 times	1888 times	510 times
Average travel time	51.8 minutes	48.8 minutes	3 minutes
Utilization	27.9%	12%	15.9%

Table 4: Results of the comparison of current situation and simulation

Table 4 shows that the scores for the average travel time are pretty close. The KPI for 'T > 45' has a decrease of 21,3% for the simulation compared to the current situation. The SAT calculates the travel time by taking the diagonal line between the stationary location and the incident location and multiplies this by a ratio (similar to Section 2.2). If the actual route deviates a lot from the diagonal line, the SAT will assume a too low travel time. This is most likely the main cause of difference between the current situation and the simulation for these two KPIs. The difference in utilization however is quite massive. The simulation scores more than twice as low as the current situation. This is partially caused by a the lower average travel times. Another possible reason for part of the difference can be that the simulation runs for only every month. This means that if an incident happens at the end of the month and takes longer than the remaining part of the month, the left over duration of the incident isn't taken to the next month as 'reserve'. However it is unlikely that these two possible explanations cause all of the difference. An unidentified mistake in the SAT or the analysis of the current situation could be the cause as well. It is important to take this difference into account when formulating an advice to ProRail (Section 9.1.3).

The average travel time KPI is fairly accurate and the "T > 45 minutes" is, taking the remarks into account, acceptable as well. The utilization value is too far off to be credible as a trustworthy number on its own. However this KPI is mainly meant as a point of consideration when comparing the runs. Section 7.1 explains more about the way this KPI is used within the decision criteria.

4.5 Limitations

As stated, the simulation has limitations to what it is capable of and what it takes into account as decision criteria. Summarized, the main limitations are:

- The simulation runs per month, excluding some parts of the duration of the incident solving procedure
- Only the SA rules are taken into account.
- It runs per five minutes instead of seconds, which gives a less realistic impression of the real life allocation.
- The utilization KPI is too far off to be used on its own (so not as a comparison aid)

To let the simulation act more realistic, some of the contact between the OVD-I and the ALs could be recreated to make the simulation more intuitive by adding more dispatching rules. Some of these rules are:

- In the current simulation it is assumed that the AL always travels back to the stationary location. However in real life it would be more logical, if an AL is already close to another incident, to travel after handling the incident to the next one. This would only be the case if finishing the incident and traveling to the next incident is shorter than the travel time for another AL. Also there is a hard limit to the hours an AL can work per day and should be taken into account as well.
- Sometimes the incident is already solved before an AL arrives at the place of incident. This means the AL can turn around and goes back to its stationary location. Within the SAT it is not assumed that this is .
- When all ALs are busy, there is no waiting list for an incident. Depending on the urgence of the incident (partially derivable from the TIS scores), some incidents will have to wait until an AL can come to the incident location. In the current simulation, the KPI ‘Times not enough ALs available’ shows for how many times such a waiting would be needed.

These additional dispatching rules clarify the limitations of the SAT. Even though it makes a better approximation, including these rules will not fully cover everything of a real life situation. It would cause the KPIs of ‘Simulation’ in Table 4 to get closer to the KPIs of ‘Current situation’. In this research these dispatching rules are not implemented. Section 9.2 underlines the possibility to look into these dispatching rules in future research.

4.6 Conclusion

Taking the limitations into account, especially the limitation on the usability of the utilization KPI, the conclusion can be drawn that comparisons between different scenarios of the current simulation can be made. Therefore the continuous simulation can be used in the SAT. Based on the comparisons between the scenarios, an advise can be brought to ProRail.

5. Scenarios for SAT

To run the simulation over multiple combinations of locations and AL number, scenarios and runs are determined. The SAT is used as a tool to retrieve KPI scores for all runs, in the end to answer the third research question: '**How should a framework for the allocation model be constructed to compare scenarios?'** In Section 5.1 the assumptions are explained, followed up by the scenarios in Section 5.2.

5.1 Assumptions

To meet the goal of this research to find the best allocation to meet the norm of "T < 45 minutes" in 95% of the incidents, multiple scenarios are run. The assumptions to set up the scenarios are based on the interview with the AL and conversations with the supervisors of ProRail.

The first assumption is to have six possible locations for a new stationary location. This means that one new stationary can be opened, according to ProRail. When a new location is opened, it means also another AL has to be hired, resulting in a total of 7 ALs. Otherwise it would be a reallocation of the current locations. In this research, the scenario of replacing stationary locations by other locations are not analyzed, as the focus is put on changing the number of ALs. However, the SAT does allow to gather KPI scores for those scenarios, by simple changing the current location settings.

The next assumption is based on the possible places for a new stationary AL location. By looking at the current map of the Netherlands, the current stationary locations (table 5) leave relative large uncovered areas. Near or in the five Dutch provinces Limburg, Zeeland, Friesland, Groningen and Gelderland, strategical locations are chosen as possibilities for new locations. These locations are mainly near large cities. Zeeland is a Province divided in long stretched pieces of land divided by water. For this province its chosen to consider the city near where all these parts of land are connected to the rest of the main land. Table 5 shows all the new possible stationary locations, with their coordinates already changed to the grid format.

new location options	place	x coordinate x	y coordinate
1	Groningen	27	32
2	Leeuwarden	21	32
3	Enschede	30	19
4	Roosendaal	10	10
5	Maastricht	20	2
6	Arhnem	22	16

Table 5 : New possible stationary locations for ALs

The last assumption is based around the maximum number of ALs that can be added to the current allocation. Currently there are always six ALs available. This number can be increased to a total of eight ALs. It is assumed that the minimal number of ALs needed is five.

5.2 Scenarios

Based on the assumptions, the scenarios for static space of solutions are determined. As stated in Table 5, there are six possible locations when opening a new stationary location. Also the total number of ALs can range from five to eight. If an AL is added, either a new location can be opened or the capacity of a current location increases from one to two ALs. If a total of eight ALs are allowed as well as one new location is opened, one or two ALs are added to a new location as well as to a current location. Another option is to add an AL to two of the current locations. (Based on conversations with ProRail, a maximum of 2 ALs per station is determined.) The static space of scenarios is defined as:

Current) Run the current situation where there is one AL at all current locations

1) Exclude one AL wherefore one of the current locations is unused. Repeat this for all locations. In this scenario no new locations are added. This results in a total of six runs
2) Add an AL to one of the six current locations. Repeat this process for all locations. In this scenario no new locations are added. This results in a total of six runs.

3) Add two ALs to two of the current locations, with a maximum of 2 ALs per location. Repeat this process until all 36 combinations are run. In this scenario no new locations are allowed.
4) Open a new stationary location with one AL, next to the current locations, resulting in a total of seven location. There are seven ALs in total. Run the model for every new location, resulting in six runs.
5) Open a new stationary location, in addition to the current locations, resulting in a total of seven locations. There are eight ALs in total, with a maximum of two ALs per location. Run the model until all 36 combinations are run.

Table 6 shows an overview of the scenarios. Total number of 90 runs for new allocation possibilities

Scenario	**Total number of Als**	**Allowing a new stationary location**	**Number of runs**
Current (situation)	6	no	1
1	5	no	6
2	7	no	6
3	8	no	30
4	7	yes	6
5	8	yes	42

Table 6: Overview of scenarios

After the settings (‘number of ALs’ and ‘allowing a new stationary location') for the chosen scenario are set correctly according to Table 6, the SAT starts running this scenario. For example if an extra AL is added to the current location (scenario 2), it means that the SAT performs six runs (over 13 months of data) to collect all the KPI scores of the scenario.

As explained in Section 4.3, the simulation tool generates only outputs for one month and repeats this 13 times to run over all data. This is repeated for all the runs within a scenarios as is explained in Figure 8 of the conceptual framework (Section 3.3). After the SAT is finished, the KPIs values are outputted to the dashboard as a summary of the performance of runs for the chosen scenario.

5.3 Conclusions

After all scenarios are determined and the tool is adjusted to run all the scenarios, the SAT is finished and ready for usage. The KPI outputs generated are put into an understandable format whereon chapter 6 will elaborately explain more.

6. Dashboard and Visualization

The results from the research can have influence on the day-to-day life of the ALs, regarding their work location. To understand choices made by managers, ProRail requests a visualization of how the SAT works. The requirements mainly entails the ease of understanding what the SAT does for stakeholders who are less knowledgeable of the details of the SAT. Besides that, an overview of the KPI outcomes from the SAT are needed to compare the different runs and situations. In Section 6.1, the functions and features of the dashboard are explained. To visualize the process, an additional component is added to the dashboard. This is discussed in the Section 6.2.

6.1 Dashboard

The SAT would be hard to understand if the variables and outcomes are not logically displayed. This is where the dashboard comes in. Appendix C shows how the total dashboard looks like. In basic, it is divided into five parts. Figure 10 shows the first part, the overview of the locations that the simulation is running over. This table shows the locations the SAT is running.

location overview while simulatin	locaties	x coordinate	y coordinate
AL1	Utrecht	15	18
AL2	Eindhoven	18	10
AL3	Rotterdam	9	16
AL4	Zwolle	23	24
AL5	Roterdam Haven	7	16
AL6	*Schiphol*	*12*	*20*
AL7			
AL8			

Figure 10: Dashboard overview of locations current simulation.

To know what locations to run, two other tables are placed on the dashboard. These denote the current locations and new locations for the model (Figure 11 and 12 respectively). Based on the settings of the SAT, the locations used in a run are gathered from these tables to from the overview as displayed in Figure 10.

new location options	place	x coordinate x	y coordinate
1	Groningen	27	32
2	Leeuwarden	21	32
3	Enschede	30	19
4	Roosendaal	10	10
5	Maastricht	20	2
6	Arhnem	22	16

Figure 11: Dashboard table with new possible locations.

current locations	place	x coordinate x	y coordinate
1	Utrecht	15	18
2	Eindhoven	18	10
3	Rotterdam	9	16
4	Zwolle	23	24
5	Roterdam Haven	7	16
6	Schiphol	12	20

Figure 12: Dashboard table with current locations.

The fourth component of the dashboard is the control menu. It has multiple functions to retrieve the needed outputs. Many intermediate created tables, when running a scenario, can be visualized. Because it costs a significant number of time to output large amounts of data from VBA to Excel, the option is given to only give only output for a selected timestamp. Figure 13 shows the control menu. The first component is the output control. As described in Section 4.3, some data changes are needed after the data is selected and adapted. This function can be turned onto get an indication of what should be changed. The SAT displays all the data it creates when doing a run. It is a long list of around 9000 rows, each indicating a timepoint. The table visualizes the incident characteristics when an incident occurs, and the occupation of the ALs. The looping check function is built in to see where a problem is when the model doesn't output anything. If the looping check is on and the output is not similar to the selected data, it means that either something is wrong with a datapoint or there is a bug in the simulation code. The looping check is thus only a function of added value when making changes to the primary data or the model. The last control in this section of output control is "KPI calculating". When this function is turned off, only the locations for each run of the selected scenario are shown, like in Figure 10. Since running the model to get the output can cost a significant amount of time, while sometimes only an overview of the locations of a run is wanted. This feature allows to get that information faster. This is especially useful when adding new scenario options.

Control menu	
Output control	
data correction	no
Simulation data	no
Looping check	no
KPI calculating	yes
Scenario control	
Number of Als (for new location 7 or more Als)	6
adding one new location (and so at least one AL)	no
visualization	
startpoint	7995
runtime	5
year/month	2018-7
on/off	on

Figure 13: Control menu to run the model.

In the second section of the control menu, the scenario is chosen. The number of ALs can be changed as well as the possibility to add a new location.(Section 5.2 explains the different scenarios more thoroughly). If “adding one new location” is turned on, only seven or eight ALs can be chosen in the previous setting. The reasoning behind this is simple, if you want to the model with a new location for five or six ALs, one or multiple of the current locations can be swapped for a new one. These scenarios can simply be run by changing the current locations, put the setting of adding a new location to “no” and select the number of ALs to five or six.

At fifth is the KPI output field. Per simulation the SAT displays all KPI values for every run. It does this for all months the SAT runs over. Appendix B shows an example of such a KPI output field.

The last part of visualization, as well as the fifth component of the dashboard, is explained in the Section 6.2. Next to these six parts, the dashboard contains 3 buttons; to run the model given the chosen settings and locations, to wipe the KPI field after a run is performed and/or to run the data selection. Also, the KPI fields are displayed.

6.2 Visualization of simulation

The last feature of the dashboard is the visualization. The answer to research question 4 ‘How should the results be visualized to form an easy to understand outcome for ProRail?’, is based on Section 3.2. A two-dimensional map of the Netherlands is displayed, divided into 1216 squares. As Figure 13 shows, the visualization can either be switch on or off and the start point, the runtime and year and month are chosen. The start point is the point in the simulation from where the outcome is displayed. The duration of the visualization determines how many steps of the simulation are displayed.

After all settings are completed, the visualization can be started. Figure 14 shows an example of a visualization. The stationary locations of the ALs are colored green indicating the available ALs and red indicates the occupied ALs. If there are two ALs working from the same stationary location and one is occupied, the square can turn red even though there is an AL available. (The SAT colors a square based on the action of allocating an AL to an incident, instead of looking at the number of available ALs at the same stationary location.) To overcome this, the locations are listed as ‘yes’ when an AL is available at the location. When an incident occurs and an AL is assigned, the stationary location of the AL turns red and the location the AL goes to turns yellow. After the Incident is solved and the AL travelled back to the stationary location, the location of the incident turns uncolored and the stationary location of the AL turns green again. This process is repeated depending on the duration and the start time. Figure 14 visualizes a timepoint during a run of the simulation as example of how the visualization looks like.

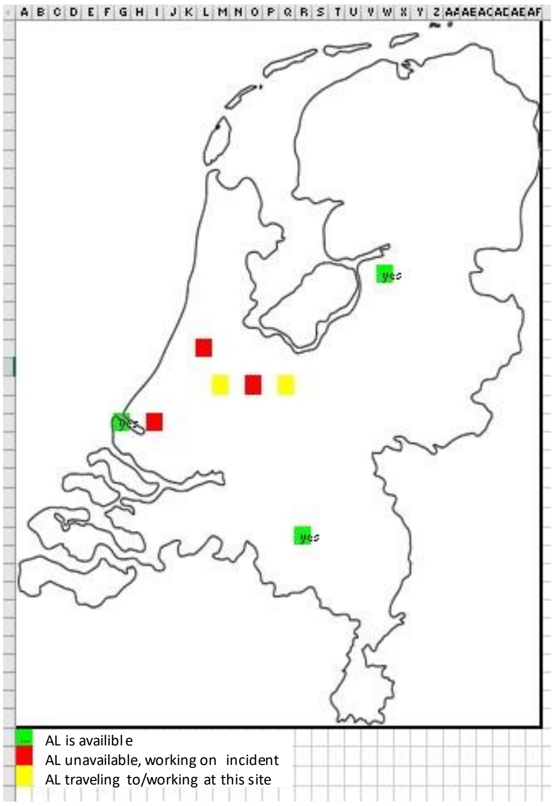


Figure 14: Example of the visualization of the simulation

The visualization has two limitations. First, it takes considerable time to wipe the map and display the status of the ALs and the incidents. The link between VBA and Excel is not fast and causes significant time to show result. This can cause long waiting times when the runtime of the visualization is large. The other limitation is the representation of the incidents when the visualization starts. Figure 14 shows three red marked AL location and only two yellow colored incident locations. When the visualization starts at a chosen timepoint, only the status of the ALs allocated after this timepoint will be represented in the sheet. This excludes the incident location status of the AL assigned before the chosen timepoint. To overcome this the start point can be set earlier, wherefore the incidents will be displayed correctly from the timepoint you want it to.

6.3 Conclusion

Taking the limitations into account, the goal of the research question is still achieved. The massive amount of simulation data is displayed in an easy to understand way without the need of knowledge about how the simulation operates. The outcomes of the SAT, expressed in the KPI fields are discussed in Chapter 7. The visualization can be used to analyze how the simulation works and what potentially would be good improvements to make the SAT more realistic or to evaluate how changes would work out in real life.

7. Results

The SAT provides KPI outcomes depending on the chosen scenario (and so the corresponding input values). In this chapter all the results gathered from the SAT are analyzed and discussed. In Section 7.1 the approach to compare the results within each scenario is explained, followed-up by the actual results of scenarios one to five in Section 7.2 to 7.6 respectively. These sections are wrapped up by Section 7.7 providing an oversight of the best run(s) per scenario.

7.1 Approach to compare results

Six scenarios are run adding up to 90 different runs performed by the SAT. There is no 'straight up' method to compare all these 90 runs. Certainly because different scenarios take into account a different number of available resources (ALs and locations). To find out which run(s) had the best KPI scores, a multiple-criteria decision analysis approach to compare results is made (Janse, B., 2022).

The first step is to establish decision criteria to compare runs. Decision criteria are principles, rules and conditions that give guidance in selecting an option (a run performed by the SAT) among several alternatives. The big advantage to use decision criteria are the quality, rationality and transparency of the decisions made to choose for a certain option. The criteria formulated to compare runs within a scenario of the SAT are:

1) Based on the KPIs. The run(s) with the highest average utilization, the lowest number of times T > 45, the lowest number of times there are not enough ALs and the lowest number of times there are not enough ALs available, is clearly the best run of the scenario .
2) Transparent trade-offs. In some cases there is not one clear dominating run. It could be that a run performs the best on the KPI with highest average utilization, but slightly worse at the other two in comparison to another run. When such comparisons has to be made, the decision is based on the relative difference between the KPIs. To illustrate, if one run scores significantly better because of a low average travel time, but slightly worse at another KPI the run is still considered the best option to choose. shortly, a look is taken at what run achieves the goal of ProRail best.
3) The importance of KPIs. The KPIs of T>45 and average travel time are considered the most important KPIs. Due to lower validity of the utilization, this KPI is considered less important when comparing runs. The 'times not enough ALs' is taken into account when the number differs significantly, because it is not taken into account within the research question. When the T>45 and average travel times of runs are very close, the 'times not enough ALs' and utilization help to choose the best run.

Next, the approach of selecting the best run for a certain scenario is decomposed into actionable steps. In the first step a table is constructed with the KPI scores per run per scenario. Appendix A. shows an overview of all these results gathered from the SAT. The second step is to compare the runs for each scenario and eliminate the dominated runs. The remaining runs per scenario are compared and a winner is selected based on criteria 2 and 3. These conclusions are presented in Sections 7.2 to 7.6.

7.2 Scenario 1

(Six runs are performed to collect the data of all possible runs in scenario one.)

Run	Locations	Avg utilization (%)	T > 45 (number)	Avg Travel time (minutes)	Times not enough ALs (number)
5	Utrecht, Eindhoven, Rotterdam, Zwolle, Schiphol	15	2022	51.1	103

Table 7: Results of the best run in scenario one.

In scenario one, five ALs are available. When comparing all six runs in appendix A, run five scores better in all KPIs as well as the 'times not enough ALs'. This means that, based on the outcomes of the SAT, the Rotterdam Haven location is the one of least importance to the performance of the ALs.

7.3 Scenario 2

(Six runs are performed to collect the data of all possible runs in scenario two.)

Run	Locations	Avg utilization	T > 45 (number)	Avg Travel time (minutes)	Times not enough ALs (number)
2	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Eindhoven	11	1937	47.5	25
6	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Schiphol	11	1868	48.5	34

Table 8: Results of the best runs in scenario two.

There are seven ALs available in scenario two, where two runs scored best overall. At run 6 there is a smaller number of cases where 'T > 45'. This difference in 'T > 45' is relatively small. However, run two scores better on the other KPIs. So, run 2 is chosen to be the best one.

7.4 Scenario 3

(36 runs are performed to collect the data of all possible runs in scenario three.)

Run	Locations	Avg utilization (%)	T > 45 (number)	Avg Travel time (minutes)	Times not enough ALs (number)
8/17	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Zwolle, Eindhoven	9	1873	45.0	14
10/27	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Schiphol, Eindhoven	9	1813	46.1	13
20/29	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Zwolle, Schiphol	9	1821	45.9	16

Table 9: Results of the best runs in scenario three.

In scenario three, eight ALs are available. Six runs remain after eliminating the obvious worse. An interesting finding in these results is concerning the orientation of the stationary locations. For run eight and seventeen, ten and 27, and 29 and twenty, the orientation of the two last locations has shifted. The KPI results are very close to each other. A possible reasoning for the difference in outcome is the way the SAT works, namely it allocates the incident to the closest available AL. In some cases it can be that the travel distance is the same for two locations, due to the use of the grid format. if this is the case, the orientation of how the locations are entered into the SAT determine which of the locations will be assigned to the incident. This means that the 'seemingly same' runs won't have the exact same KPI outcome. To overcome this, the average of the KPIs is calculated for the runs where the orientation of locations does not matter, as shown in table 9.

When comparing run 8/17, 10/27 and 29/20, runs 8/17 have the lowest travel time and run 10/27 the lowest 'T > 45'. Run 29/20 does not stand out in any of the KPI's. Taking into consideration that bother runs 10/27 and 8/17 are really close to each other. Runs 10/27 overall score better except on the average travel time, where run eight/seventeen scores significantly better. Concluding, adding an AL in Eindhoven and either Zwolle or Schiphol would be the best option.

7.5 Scenario 4

(Six runs are performed to collect the data of all possible runs in scenario four.)

Run	Locations	Avg utilization (%)	T > 45 (number)	Avg Travel time (minutes)	Times not enough

					ALs (number)
6	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Arnhem	10	1548	42.4	26

Table 10: Results of the best run in scenario four.

In scenario four, seven ALs are available as well as one new stationary location. When comparing all six runs in appendix A, run six scores better in all KPIs as well as the 'times not enough ALs'. This means that, based on the outcomes of the SAT, Arnhem would be the most favorable place to add if there are seven ALs and a new stationary location would open up.

7.6 Scenario 5

(36 runs are performed to collect the data of all possible runs in scenario five.)

Run	**Locations**	**Avg utilization (%)**	**T > 45 (number)**	**Avg Travel time (minutes)**	**Times not enough ALs (number)**
24	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Arnhem, Zwolle	9	1563	42.0	14
36	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Arnhem, Schiphol	9	1487	42.1	14

Table 11: Results of the best runs in scenario five.

In scenario five, eight ALs are available as well as a new stationary locations. Table 11 shows, the two runs to compare after eliminating all dominated runs. Where run 24 has a slightly lower average travel time, run 36 has a more significant decrease in 'T > 45'. Therefore run 36 is considered the best run. Concluding, in scenario five it would be best to add an AL to location Schiphol and open up a location in Arnhem with one AL.

7.7 Result overview

Scenario	Run	Number of ALs	New location	Locations	Avg utilization (%)	T > 45 (%)	Avg Travel time (minutes)	Times not enough ALs (number)
1	5	5	No	Utrecht, Eindhoven, Rotterdam, Zwolle, Schiphol	15	44.6	51.1	103
2	2	7	No	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Eindhoven	11	42.7	47.5	25
3	8/17	8	No	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Zwolle, Eindhoven	9	41.3	45.0	14
3	10/27	8	No	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Schiphol, Eindhoven	9	40.0	46.1	13
4	6	7	Yes	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Arnhem	10	34.1	42.4	26
5	36	8	Yes	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Arnhem, Schiphol	9	32.8	42.1	14

Table 12: Overview of all results

Table 12 summarizes the final results of all scenarios. Figure 15 visualizes these results in graphs to make comparisons between the scenarios (and the current situation) easier. The percentage of 'T > 45' is calculated to better understand what the number means when drawing conclusions.

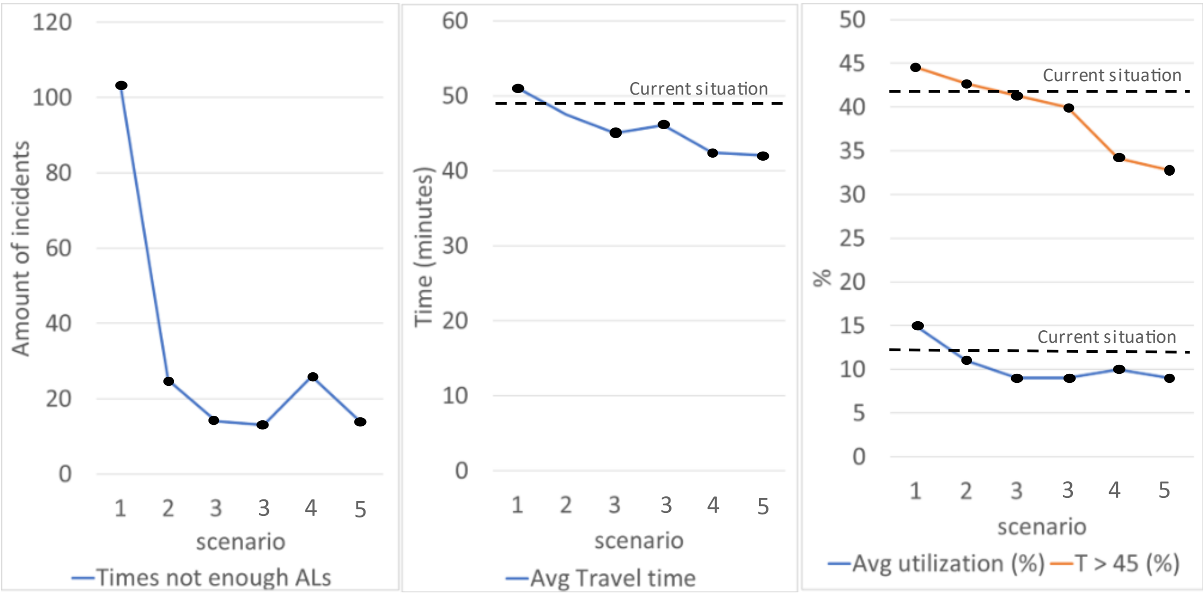


Figure 15: Overview results in graphs

Looking at Figure 15, scenario 1 stands out. When comparing it to the current situation and other runs it is obviously worse. This means that decreasing the number of ALs by 1 will have major impact on the incident handling and therefore is considered unwanted. If the situation would occur where only 5 ALs are available, it is best to exclude the stationary location at Rotterdam Haven.

Instead of decreasing the number of ALs by 1, in scenarios 2 and 4 an AL is added. In scenario 4 a new location is opened as well. When comparing these two scenarios they score fairly similar on the KPI's of 'Times not enough ALs' and 'Avg utilization'. However run 4 stands out positively in the average travel time and especially in the 'T>45'. From this is can be concluded that opening a new locations is very favorable. Arnhem turns best place to open up a location. Run 4 is also a big improvement over the current situation.

Jumping from adding one AL to adding two ALs without opening a new location, an improvement can be seen in all KPI scores, except of the utilization. (Scenarios 2 and 3 are compared for this). In both scenarios 2 and 3, adding one AL to the location in Eindhoven would be favorable. When two ALs are added, allowing a new location as well, Schiphol turns out to be an interesting location to add an AL as well. When opening a new locations as well, the KPI scores mostly improve for the average travel time and the 'T>45'. (Scenarios 4 and 5 are compared for this).

8. Conclusion and implementation

This chapter concludes the findings of the research in Section 8.1. Based on the outcomes of chapter 7, an answer is formulated to the main research question. Based on the conclusions, Section 8.2 provides recommendations for implementation to ProRail.

8.1 Conclusion

To recap, the goal of the research is to explore the unused potential in allocating ALs to improve the current AL allocation, by using data analysis and modelling. Therefore, in Section 1.4.1, the main research question is formulated as: **'How should the ALs be allocated, based on provided data, to lower their travel times below 45 minutes in 95% of the time, taking the utilization of their work shifts into account?'**
To form an answer to this question, a research methodology is chosen as explained in Section 1.4.2. Based on this methodology, research questions are formulated in Section 1.4.3. To answer the main research question, these question must be answered first.

Chapter 2 answer research question 1: **'To what degree does the current allocation meet the norm?'** by explaining how the current situation is set up and formulates approaches to determine the KPI values for the current state. As stated in the conclusion of Chapter 2, ProRail currently is not reaching its goal of travel times below 45 minutes for 95% of the incidents. With an average travel time higher than 45 minutes and more than half of the incidents having a travel time of over 45 minutes. The conclusion underlines the importance to look into the other research questions.

To achieve the goal(/norm) of this research to lower the travel times of ALs below 45 minutes in 95% of the times, research question two and three are answered. The second research quesion: **'How can the chosen allocation model best be constructed?'** is answered by constructing a continuous simulation in Chapter 4. The choice to construct this type of simulation is based on the literature of Section 3.1. After the simulation is set up, it is validated in Section 4.4. To do so, the current situation is run by the simulation and the output is compared to the current situation analysis. As turns out, the output of the simulation is not valid on its own. However, it can still be used to compare simulations runs and so it is chosen to use the simulation in the rest of the research.

The simulation itself can only do 1 run. Therefore the simulation is used within a framework to go over all runs within the scenario's, as Chapter 5 explains. It forms the answer to the third research question: **'How should a framework for the allocation model be constructed to compare scenarios?'**. The simulation in combination with the framework forms the SAT. Based on record data and the settings related to a certain scenario, the SAT generates an output in the form of KPIs for all runs within a scenario. The KPIs are used to compare runs and scenarios to conclude what situation would be best for ProRail.

To understand the how the SAT works, the outcomes it generates and how it should be controlled, a dashboard is created, based on the literature in Section 2.2. Chapter 6 explains what the purpose of each component of the dashboard is. It answers research question 4: **'How should the results be visualized to form a easy to understand outcome for ProRail'**. One of the requirements of ProRail is to make the tool easy to understand. To explain the steps the simulation makes, a visualization is added to display an animation of the allocation of ALs.

Based on the KPI outcomes (appendix A), the best runs are selected per scenario in Chapter 7 and compared to each other and the current situation. Table 12 provides an oversight of these runs and Figure 15 displays them within a graph for easier comparison.
After the comparison of runs, the fifth research question is answered: **'What is the best allocation method?'** The answer is based on the conclusion in Section 7.7. Opening a new location (scenario 4 and 5) show significant improvements of KPI scores compared to not opening a new location (scenario 2 and 3). The area around Arnhem is the most interesting to take a look at to open a new stationary location.

Adding 2 ALs shows a similar change in KPI scores for when comparing scenario 2 and 3, and 4 and 5. It does improve the KPIs scores but also has the drawback of a decreased utilization. Therefore scenario four, adding a new location with one AL in Arnhem, is considered the best allocation method.

To conclude the research, the answer formulated to the Main research question**: 'How should the incident general leaders (AL) be allocated, based on provided data, to lower their travel times below 45 minutes in 95% of the time, taking the utilization of ALs into account?'**. In none of the scenarios the norm to have a travel time lower than 45 minutes for 95% of the cases is reached. As explained in Section 4.4, the KPI values from the SAT are not very accurate. This makes it harder to formulate a valid answer to the research question. To come closest to the defined norm, scenario 5 would be best by opening a new location in Arnhem and adding an AL to the location of Schiphol.
To reach the research goal according to the SAT, more ALs and/or more locations are needed. As these scenarios would not be feasible for ProRail, they are not tested within this research. However, taking the answer to the fifth research question in mind, the main finding of the research is to explore the possibilities of opening a new location in Arnhem (scenario 4). This is seen as the most effective change to the current allocation.

8.2 Implementation

The implementation recommendations are written for ProRail to know what potential next steps would be. These recommendations are based on the conclusions of Section 8.1 and the limitation of the research as defined in Chapter 9. Depending on the resources ProRail has available, possibilities can be explored.

The main recommendation of the research to ProRail is to look into the possibilities of setting up a stationary location in Arnhem. Even though this would result in additional costs for the locations as well as hiring a new AL, it causes a massive improvement in the KPI scores. The norm set will not be met with this change (taking the validity of the outcomes of the SAT into account), but it would be the most substantial change to reach the norm.
To overcome the additional costs of hiring a new AL, a look can be taken into reallocating an AL to Arnhem. As scenario 1 indicated, reallocating an AL from Rotterdam Haven to Arnhem would probably be the best step. This change can be explored further.

In case of only 5 available ALs, the Rotterdam Haven location turns out to be the least necessary to cover. When an AL is unavailable, it is advised to reallocate the AL of Rotterdam Haven to the temporarily uncovered stationary location.

When ProRail chooses to look further the recommendations, it is important to consider the limitations of Chapter 9.

9. Limitations and further research

There are a number of limitations to the research to take into account. Section 9.1 explains these limitations thoroughly and Section 9.2 explains the future research possibilities .

9.1 limitations

Being aware of the limitations is important as points of consideration to this research. The limitations are divided into three categories; limitations to SA, to the design and the final version of the SAT. These are discussed in Sections 9.1.1, 9.1.2 and 9.1.3 respectively. Underneath the limitations, the cursively marked sentences state the implications of the limitations.

9.1.1 Limitations to the design of the SAT

To create the SAT, choices are made. Some are made before the construction of the SAT, like the chosen primary data. The SAT bases its KPI results on only 13 month of data. Also the data is a few years old. Even though it is logical not to use the data collected during COVID-19, it results in older, maybe less representative data. This, in its turn, could cause less representative outcomes of the SAT. *For the conclusion of the research it can mean that it is less applicable to the present than it was to 3 years ago. It means ProRail should consider if the chosen data still represents the present.*

Another design choice is the usage of a grid format. After the SAT was constructed, it turned out that using a grid is not necessary. It contributes to inaccuracy of the simulation, because the precise coordinates of the ALs and incident locations are calculated to a way less accurate grid format. Section 3.2 explains how the roster is used.
Next, to calculate the closest AL, the diagonal distance between the incident and the ALs is calculated. In real life it is not possible to travel over the diagonal line. Therefore the AL assumed to be closest to the incident possibly is does not have the shortest real life travel time. *These two inaccuracies around the calculations of the travel distance cause less reliable KPIs and influences the reliability of the final advice as well. In future development of the SAT these could fairly easily be resolved.*

The last design decision to look at is the form of simulation. The SAT is based on a continuous simulation as explained in Section 2.3. A lot of calculations are made due to running over all timepoints next to taking the big number of incidents into account. If DES would have been used, the number of calculations could possibly be reduced by not running over all possible timepoints. This would make the SAT more efficient and faster. *The use of the continuous simution does not have influence on the reliability/usability of the outcomes, only on the speed of the SAT.*

Other design choses are made during the construction of the SAT. The first one is to run the simulation per month instead of per year. Due to the calculation time it takes to run 13 months instead of only a month, it is chosen to run the simulation per month to allow easier development of the simulation. This does bring a drawback as explained in Section 4.1. Shortly, it brings unwanted error to the results of the SAT.
Another limitation caused to decrease the computational time is to let the simulation run per 5 minutes instead of per second, as explained in Section 4.2. This decreases the number of calculations by 300 times, which is a massive. *It also means the SAT simulates the allocation of ALs less realistic.*

Next to the limitations due to computational time, the SAT only works for specific scenarios, as explained in Section 5.2. This limits the possibilities of the tool for other uses than the goal set for this research. This is a holdback for future research. *It does not affect the outcomes of the SAT for current run scenarios however and is not seen as a limitation for the current research.*
Also the way the travel times are determined form a limitation to the research validity. In early stages of the research, it was assumed that the travel times are available. However it turned out that these are not accessible. To still determine the travel times, a speed-distance ratio was determined to calculate the estimated travel time. This is not as accurate as the real travel time. Also the assumption is made that the same ratio holds for all areas in the Netherlands. This is not realistic since travelling in a city mostly costs more time than traveling over the highway. T*his introduces another margin of error to the outcomes of the SAT*

9.1.2 Limitations of using SA

The SA system ProRail uses to assign ALs to incidents uses a limited set of dispatching rules as explained in Section 3.1. The SAT is based on the SA, wherefore some limitations rise. Section 4.5 explains two drawbacks. The SAT assumes the AL will always travel back to the stationary location after which it is available again. Also if an incident is already solved, the AL won't turn back immediately. Instead it will still go to the incident location. These two limitations make the allocation less realistic. Next to these two downsides, there are numerous different dispatching rules to use that could be more efficient/effective. An example is to replace an AL to another incident even though the incident is not completely solved yet.

Another limitation is based on the capacity of ALs. When all ALs are occupied, the SAT will simply overwrite the closest AL to the new incident. This means that the remaining duration of the incident and/or the travel time is neglected. In reality this is not possible.

Both of the above standing limitations cause a less realistic simulation of the way ProRail allocates ALs. This decreases the credibility of the results from the SAT. As stated in Section 9.2, it is recommended to add dispatching rules in future research.

9.1.3 Limitations to the final version of the SAT

These limitations are discovered during the construction of the SAT or when analysing the results gathered from the SAT.
The first limitation is the difference between the actual and simulation KPI scores of the current situation. Section 4.4 explains possible reasons why these differences could be caused. The KPI scores of the simulation therefore are only considered usable when comparing it to KPI scores of other scenarios and runs. *Since the KPI scores can't be used to rate the scenarios on their own, it is hard to rate how good a proposed scenario actually is. Therefore, formulating a valid answer to the main research question based on the KPI scores of the SAT is only possible with the comparison of scenarios/runs.*

Another point of consideration is the orientation of how stationary locations are put in the SAT. Section 7.4 describes a possible reason for the slightly different KPI scores when the orientation of locations is different. *Since the output only differs a little bit, and should be the same, the average is taken of these seemingly same runs.*

Third, the SAT does not correct all mistakes in the primary data like explained in Section 4.2. Ideally all possible mistakes would be solved automatically. *This only makes it harder to prepare the data well, but does not influence the outcomes of the SAT.*

At last, the visualization takes a considerable amount of time to display. As Section 6.2 states, the link between VBA and Excel is not fast and causes significant time to show results. This limits the ease of getting a good oversight of how the SAT works. Another small limitation to the visualization is the inability to always correctly colour the stationary location when two ALs are stationed at the same location. To overcome this, a "yes"/"no" has been added.
Also the visualization tool only shows the marked dots of new incidents When an incident occurred before the selected time and is still ongoing, this is not showed on the map. This could be more troubling but can be overcome by extending the visualization interval. *These limitations only hinder the usability of the visualization and ttherefore are considered as practical inconveniences.*

9.1.4 Conclusion

Concluding, there are quite a lot of limitations to this research. Some do hinder the outcomes of the research and ProRail should take these into account when deciding to implement changes based on this research. The biggest limitation is the difference between the actual and simulation KPI scores as the KPI outcomes from the SAT are not valid on its own. This difference can be caused by some of the other limitations.

9.2 Further research

To further look into reallocation possibilities of ALs with the SAT, the limitations stated in Section 9.1.1 and 9.1.3 should be resolved. As stated in Section 9.1.4, the most important limitation of the SAT is the difference between the actual KPI scores and the KPI scores calculated by the SAT. Especially the difference in the KPI score of the utilization is troubling (Section 4.4). Resolving this difference will give more credible outcomes the SAT.

Next to resolving the limitations, expanding the functionality of the SAT would be good to look into for further research. Currently, only five scenarios are tested as is requested by ProRail. There are numerous other scenarios to test as well. For example, in real life it could be possible that only four ALs are available. In future research these could be tested as well. Another suggestion is to change the current stationary locations while remaining 6 ALs, as Section 5.1 suggests
Also analysing the behaviour of the SAT by taking a look at the visualization can bring valuable insights into further improvements of the SAT or new topics to research.

As main advice for ProRail for further research is to look into the dispatching rules. The SA mainly bases its decision on the rule ‘allocate incident to closest available AL’ (Section 3.1). An AL is available again when the incident in solved. Most probably, this rule on its own does not result in the best allocation of ALs. A first example to potentially look into is intermediate switching of ALs on an incident. This is currently unexplored, but could potentially lead to lower travel times.
As another example, currently the OVD-I still makes a lot of choices how to allocate the ALs better when incidents occur. Implementing part of the choices the OVD-I makes into the SA will also make it more intuitive. Section 9.1.2 further explains some examples.

As last point of advice for further research is to look into the data collection. Currently the travel times are not registered into the Spoorweb data. Though the dataset is considered big, it could potentially be expanded. Also the data collected during corona has potential deviations from the data before or after this period. Exploring these differences could give interesting insights.

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Appendix A - Overview of all results

Scenario	Run	Number of ALs	New location	Locations	Avg utilization	Times > 45	Avg. time travel	Times not enough ALs
Current situation	1	6	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol	12	1888	48,8	58
1	1	5	no	Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol	15	2150	53,7	115
1	2	5	no	Utrecht, Rotterdam, Zwolle, Rotterdam Haven, Schiphol	16	2276	60,1	120
1	3	5	no	Utrecht, Eindhoven, Zwolle, Rotterdam Haven, Schiphol	15	2143	53,8	106
1	4	5	no	Utrecht, Eindhoven, Rotterdam, Rotterdam Haven, Schiphol	16	2116	59,9	113
1	5	5	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Schiphol	15	2022	51,1	103
1	6	5	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven	16	2593	59,1	120
2	1	7	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Utrecht	11	1925	48,3	32
2	2	7	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Eindhoven	11	1937	47,5	25
2	3	7	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Rotterdam	11	1936	49,3	38
2	4	7	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Zwolle	11	1940	47,5	33
2	5	7	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Rotterdam	11	1989	50,6	41
2	6	7	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Schiphol	11	1868	48,5	34
3	1	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Eindhoven, Utrecht	9	1865	46,3	15
3	2	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Rotterdam, Utrecht	9	1867	47,3	18
3	3	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Zwolle, Utrecht	9	1875	46,1	15
3	4	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Rotterdam Haven, Utrecht	9	1896	47,9	18
3	5	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Schiphol, Utrecht	9	1833	47,2	18
3	6	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Utrecht, Eindhoven	9	1871	46,3	12
3	7	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Rotterdam, Eindhoven	9	1867	46,2	12

3	8	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Zwolle, Eindhoven	9	18 70	44,9	12
3	9	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Rotterdam Haven, Eindhoven	9	19 07	47,0	12
3	10	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Schiphol, Eindhoven	9	18 20	45,9	12
3	11	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Utrecht, Rotterdam	9	18 78	47,9	19
3	12	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Eindhoven, Rotterdam	9	18 70	46,8	16
3	13	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Zwolle, Rotterdam	9	18 75	46,4	17
3	14	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Rotterdam Haven, Rotterdam	9	19 34	49,1	21
3	15	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Schiphol, Rotterdam	9	18 34	47,7	19
3	16	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Utrecht, Zwolle	9	18 82	46,3	16
3	17	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Eindhoven, Zwolle	9	18 76	45,1	15
3	18	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Rotterdam, Zwolle	9	18 73	46,1	17
3	19	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Rotterdam Haven, Zwolle	9	19 11	46,9	18
3	20	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Schiphol, Zwolle	9	18 25	45,8	16
3	21	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Utrecht, Rotterdam Haven	9	19 22	48,9	20
3	22	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Eindhoven, Rotterdam Haven	9	19 18	47,9	17
3	23	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Rotterdam, Rotterdam Haven	10	19 47	49,6	21
3	24	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Zwolle, Rotterdam Haven	9	19 27	47,6	18
3	25	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Schiphol, Rotterdam Haven	9	18 72	48,7	21
3	26	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Utrecht, Schiphol	9	18 26	47,5	17

3	27	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Eindhoven, Schiphol	9	18 06	46,2	14
3	28	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Rotterdam, Schiphol	9	18 13	47,4	18
3	29	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Zwolle, Schiphol	9	18 16	46,0	15
3	30	8	no	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Rotterdam Haven, Schiphol	9	18 41	48,1	18
4	1	7	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Groningen	10	18 64	46,8	37
4	2	7	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Leeuwarden	11	19 39	47,4	36
4	3	7	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Enschede	11	19 10	47,8	33
4	4	7	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Roosendaal	10	15 65	45,8	32
4	5	7	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Maastricht	11	18 57	47,1	34
4	6	7	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Arnhem	10	15 48	42,4	26
5	1	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Groningen, Rotterdam	9	17 87	44,0	16
5	2	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Leeuwarden, Utrecht	9	18 52	44,8	16
5	3	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Enschede, Utrecht	9	18 28	45,9	16
5	4	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Roosendaal, Utrecht	9	15 34	44,2	13
5	5	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Maastricht, Utrecht	9	17 72	44,5	16
5	6	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Arnhem, Utrecht	9	15 53	42,5	14
5	7	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Groningen, Eindhoven	9	17 87	42,8	12
5	8	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Leeuwarden, Eindhoven	9	18 53	43,6	12
5	9	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Enschede, Eindhoven	9	18 34	45,0	12
5	10	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Roosendaal, Eindhoven	9	15 50	43,8	10
5	11	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Maastricht, Eindhoven	9	17 99	45,2	13

5	12	8	yes	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Arnhem, Eindhoven	9	1543	41,9	11
5	13	8	yes	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Groningen, Rotterdam	9	1792	44,5	18
5	14	8	yes	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Leeuwarden, Rotterdam	9	1855	45,3	18
5	15	8	yes	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Enschede, Rotterdam	9	1835	46,3	18
5	16	8	yes	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Roosendaal, Rotterdam	9	1584	45,5	17
5	17	8	yes	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Maastricht, Rotterdam	9	1785	45,2	19
5	18	8	yes	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Arnhem, Rotterdam	9	1548	42,6	15
5	19	8	yes	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Groningen, Zwolle	9	1815	44,6	19
5	20	8	yes	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Leeuwarden, Zwolle	9	1855	46,0	19
5	21	8	yes	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Enschede, Zwolle	9	1855	46,0	18
5	22	8	yes	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Roosendaal, Zwolle	9	1550	42,9	14
5	23	8	yes	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Maastricht, Zwolle	9	1784	43,4	16
5	24	8	yes	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Arnhem, Zwolle	9	1563	42,0	14
5	25	8	yes	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Groningen, Rotterdam Haven	9	1844	45,7	21
5	26	8	yes	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Leeuwarden, Rotterdam Haven	9	1906	46,5	20
5	27	8	yes	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Enschede, Rotterdam Haven	9	1885	47,4	19
5	28	8	yes	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Roosendaal, Rotterdam Haven	9	1610	46,3	18
5	29	8	yes	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Maastricht, Rotterdam Haven	9	1837	46,4	21
5	30	8	yes	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Arnhem, Rotterdam Haven	9	1594	43,6	15

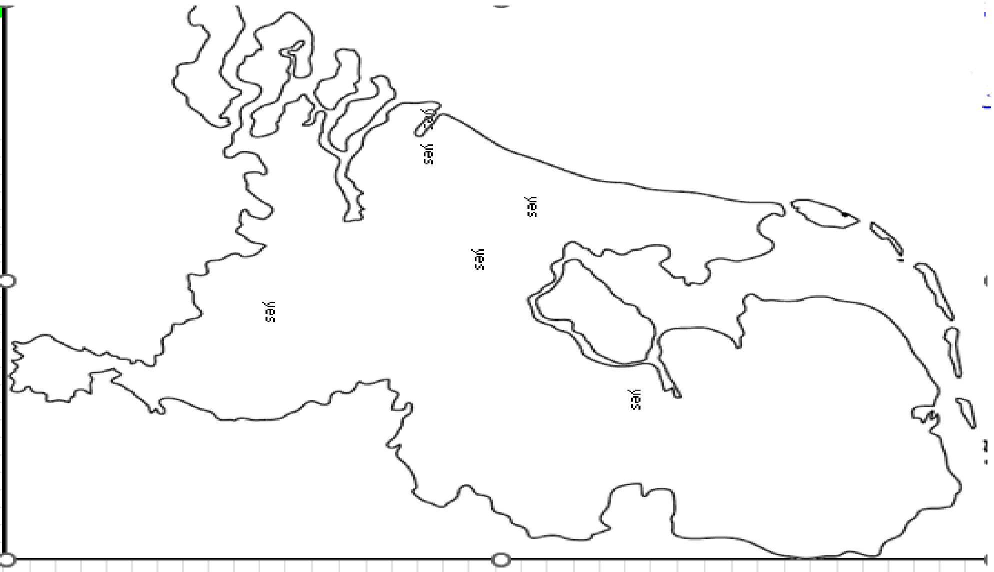
5	31	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Groningen, Schiphol	9	17 28	43,9	16
5	32	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Leeuwarden, Schiphol	9	17 92	44,8	16
5	33	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Enschede, Schiphol	9	17 68	45,7	16
5	34	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Roosendaal, Schiphol	9	14 77	44,2	14
5	35	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Maastricht, Schiphol	9	17 18	44,4	16
5	36	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Arnhem, Schiphol	9	14 87	42,1	14
5	37	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Groningen, Groningen	9	18 64	46,7	24
5	38	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Leeuwarden, Leeuwarden	9	19 41	47,4	22
5	39	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Enschede, Enschede	9	19 04	47,5	21
5	40	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Roosendaal, Roosendaal	9	15 62	45,6	18
5	41	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Maastricht, Maastricht	9	18 58	47,0	20
5	42	8	ye s	Utrecht, Eindhoven, Rotterdam, Zwolle, Rotterdam Haven, Schiphol, Arnhem	9	15 38	42,1	13

Appendix B - Example Dashboard KPI output

month	year	utility AL1	utility AL2	utility AL3	utility AL4	utility AL5	utility AL6
2018	6	13,48566308	11,80555556	13,6312724	12,21998208	5,342741935	8,99417562
2018	7	18,71639785	16,01702509	16,66666667	13,04883513	7,952508961	14,3817204
2018	8	15,87141577	11,41353047	17,50672043	11,80555556	5,566756272	12,7128136
2018	9	14,2921147	13,5640681	14,74014337	10,69668459	4,883512545	11,6263440
2018	10	14,79614695	13,5640681	17,77553763	13,54166667	6,182795699	13,2728494
2018	11	16,6890681	17,23790323	15,08736559	9,386200717	5,297939068	12,3767921
2018	12	10,08064516	13,16084229	14,07930108	9,677419355	5,443548387	9,34139784
2019	1	16,39784946	14,74014337	19,79166667	15,66980287	6,944444444	14,3033154
2019	2	16,03942652	12,5	16,52105735	11,61514337	5,309139785	13,76568
2019	3	13,59767025	18,73879928	14,68413978	14,39292115	3,55062724	10,8982974
2019	4	15,86021505	13,62007168	16,50985663	8,355734767	6,474014337	14,0008960
2019	5	11,98476703	9,778225806	12,17517921	13,08243728	3,125	10,9991039
2019	6	14,2921147	10,84229391	13,765681	15,15456989	7,381272401	16,8570788

	utility AL7	utility AL8	times traveltime > 45 min	average traveltime	longest traveltime	shortest traveltime
7	0	0	126	48,44594595	240	0
3	0	0	178	51,89189189	230	0
2	0	0	152	49,69444444	215	0
9	0	0	144	50,83860759	240	0
6	0	0	157	50,31767956	255	0
1	0	0	139	46,15068493	215	0
9	0	0	117	46,72297297	220	0
1	0	0	181	49,43645084	250	0
1	0	0	140	44,25207756	215	0
9	0	0	166	54,63017751	230	0
6	0	0	135	45,91780822	230	0
4	0	0	104	45,15734266	220	0
5	0	0	149	51,48097826	240	0

Appendix C - Simulation Allocation Tool'



if an AL) availible
AL unavailible, working at an incident
AL traveling to/working at this site

location overview while simulatin	locaties	x coordinate	y coordinate
AL1	Utrecht	15	18
AL2	Eindhoven	18	10
AL3	Rotterdam	9	16
AL4	Zwolle	23	24
AL5	Roterdam Haven	7	16
AL6	*Schiphol*	*12*	*20*
AL7			
AL8			

new location options	place	x coordinate	y coordinate
1	Groningen	23	25
2	Friesland	24	25
3	Zeeland	26	25
4	Noord-Brabant	27	25
5	Limburg	28	25
6	Drente East	29	25

Fill all options

Control menu	
Output control	
data correction	no
Simulation data	no
Looping check	no
KPI calculating	yes
Heuristic control	
amount of Als (for new location 7 or more Als)	6
adding one new location (and so at least one AL)	no
visualization	
startpoint	7995
runtime	5
year/month	2018-7
on/off	off

Allocation (only over single chosen allocation)

Clear KPI field

KPI's

month	year	utility AL1	utility AL2	utility AL3	utili
2018	6	86.51433692	88.19444444	86.3687276	
2018	7	81.28360215	83.98297491	83.33333333	
2018	8	84.12858423	88.58646953	82.49327957	
2018	9	85.7078853	86.4359319	85.25985663	
2018	10	85.20385305	86.4359319	82.22446237	
2018	11	83.3109319	82.76209677	84.91263441	
2018	12	89.91935484	86.83915771	85.92069892	
2019	1	83.60215054	85.25985663	80.20833333	
2019	2	83.96057348	87.5	83.47894265	
2019	3	86.40232975	81.26120072	85.31586022	
2019	4	84.13978495	86.37992832	83.49014337	
2019	5	88.01523297	90.22177419	87.82482079	
2019	6	85.7078853	89.15770609	86.234319	
2018	6	10.03204338	4.372223521	4.801032985	
2018	7	12.35841933	5.970326409	8.758679498	
2018	8	10.9068323	7.709011944	7.930367505	
2018	9	8.94447834	4.177362894	7.037525477	
2018	10	12.55673222	6.526667462	6.260414187	
2018	11	12.78423446	4.153056463	7.904278463	
2018	12	9.707544851	2.975778547	6.704912155	
2019	1	11.41894422	7.826086957	10.01848429	
2019	2	10.00492854	8.441637313	7.735006637	
2019	3	8.100254268	8.984375	6.641184902	
2019	4	11.6418657	4.998235917	9.371554576	
2019	5	6.845380565	11.32169576	7.852138198	
2019	6	12.5425438	6.577533723	8.507535246	
2018	6	10.07274072	5.556869236	3.693379791	

current locations	place	x coordinate	y coordinate
1	Utrecht	15	18
2	Eindhoven	18	10
3	Rotterdam	9	16
4	Zwolle	23	24
5	Roterdam Haven	7	16
6	Schiphol	12	20

Fill all locations

ty AL4	utility AL5	utility AL6	utility AL7	utility AL8	times traveltime > 45 min	average
87.78001792	94.65725806	91.00582437	0	0	126	4
86.95116487	92.04749104	85.61827957	0	0	178	
88.19444444	94.43324373	87.28718638	0	0	152	4
89.30331541	95.11648746	88.37365591	0	0	144	5
86.45833333	93.8172043	86.72715054	0	0	157	5
90.61379928	94.70206093	87.62320789	0	0	139	4
90.32258065	94.55645161	90.65860215	0	0	117	4
84.33019713	93.05555556	85.69668459	0	0	181	4
88.38485663	94.69086022	86.234319	0	0	140	4
85.60707885	96.44937276	89.10170251	0	0	166	5
91.64426523	93.52598566	85.99910394	0	0	135	4
86.91756272	96.875	89.00089606	0	0	104	4
84.84543011	92.6187276	83.14292115	0	0	149	5
11.76765148	1.477608547	17.9548157	0.585849482	0	5	2
16.00831601	2.256328027	27.25199544	0.869958197	0	3	2
11.73967459	1.952723535	24.93702771	1.144216608	0	4	2
13.27074347	1.041195111	20.5346294	0.676589986	0	3	2
12.24541111	0.949796472	25.81736189	0.427446569	0	1	2
16.447111	1.848049281	21.88395904	0.280804223	0	3	2
11.68376282	0.926972643	19.23076923	0.314606742	0	1	2
15.02190157	1.964367291	27.50642674	0.869958197	0	0	2
11.04477612	1.813205611	27.87167001	0.506585613	0	6	2
19.15120779	0.972630627	18.94484412	0.847170451	0	11	2
11.10004978	2.726958923	24.03445402	0.81300813	0	2	2
9.653647752	1.489144026	18.86566369	0.699300699	0	9	
11.11387679	2.162718847	21.04121475	1.224489796	0	1	2
11.93580742	0.416151164	15.06637453	0.450045005	0	0	1

Appendix D - Interview AL

General information: Interview with an AL working at the ICB location of Eindhoven. He works as an AL for nine years, first at Roterdam and later reallocation to Eindhoven

Q1: Waar bevinden jullie je vooral als er geen gemeld incident is waar u naartoe moet?

> **A1:** Meestal andere werkzaamheden of controlerondjes aan het rijden of wachten totdat er eventueel wel wat gebeurd.

Q1.1: Hoe groot is de cirkel van dit rondje en in hoeverre is het evenredig verdeeld?

> **A1.1:** In eerste plaats hangt het af of er een dagdienst of nachtdienst is. Voor nachtdiensten worden AL's opgeroepen vanuit hun huis. De meeste Als per regio wonen binnen een half uur de ICB locatie af. De andere diensten worden meestal vanuit de standplaats uitgevoerd of elders rondom het ICB dat maximaal een half uurtje af is gelegen van de ICB locatie. Hierbij is een half uur rijden al lang naar inschatting. De post in Eindhoven gaat dus niet zomaar naar zuid Limburg toe.

Q2: Hoe ervaart u de werkdruk? Zijn er veel piekmomenten?

> **A2:** Het 'hollen of stilstaan' hoort erbij. Het verschilt erg per moment, van weekenden van hot naar her, maar soms gebeurd er ook helemaal niks. De ICB locatie Eindhoven merkt niet echt knelpunten qua capaciteit, ze komen met de planning prima rond en kunnen vaak snel en accuraat handelen bij de incidenten.

Q3: Als er een nieuwe ICB locatie zou komen, wat zouden dan goede mogelijke locaties zijn om deze locatie te vestigen? (voor het hele land).

> **A3:** Voor grotere calamiteiten is het nu redelijk goed gedekt voor het zuiden van Nederland. Op de maaslijn na, gebeuren er weinig grote calamiteiten in het verdere zuiden. De meeste van deze calamiteiten gebeuren vooral rondom Eindhoven. De provincies Zeeland, Friensland en Groningen kunnen wel af en toe voor problemen zorgen. Het is lang reizen voor een AL om hier te komen. De afweging voor een nieuwe locatie is hier vooral tussen de effectiviteit en de efficiëntie voor het vestigen van een AL.

Q4: Hoe ziet het 'slim allermeren'-systeem er precies eruit?

> **A4:** Eerst waren de incidenten regionaal verdeeld. Dat houdt in dat alle incidenten die in de regio van een bepaalde AL plaats vinden, door betreffende AL opgelost moeten worden. Dit had als grote nadeel dat een indicent veel dichter bij een andere AL kon zijn, die deze dus niet oppakte. Daarnaast diende je collega (degene die vroege dienst draait als de andere AL de lade dienst draait, en omgedraaid) als back-up. Als de college dan ook uitgerukt was voor back-up om de capaciteit in de regio te verhogen, mag er volgens het contract geen AL meer de volgende ochtend gaan werken. Voor de contractverandering was dit nog wel mogelijk, maar tegenwoordig is het draaien van zoveel uur aan een stuk door niet meer toegestaan voor een AL bij Prorail.
>
> Om dit probleem op te lossen werd 'slim allermeren' gebruikt. Hierbij is het toewijzen van incidenten aan AL niet meer regionaal bepaald, maar voor het hele land. De dichtstbijzijnde, beschikbare AL wordt toegewezen aan het incident, afhankelijk van het type calamiteit en wat er precies nodig is. De AL staat gekoppeld aan een voertuig bij een dienst, waardoor snel verplaatsen goed mogelijk is. Voor het 'slim allermeren'-systeem werd er nog veel overlegt tussen ALs, nu gebeurd dat vooral via de OVD-i. Het 'slim allermeren' is een goede stap richting een veel flexibeler allocatiesysteem, maar er zijn zeker nog veel verbeteringen mogelijk wat betreft het toewijzen van AL. Het systeem zou een stuk van de keuzes over kunnen nemen die nu door de ALs en het OVD-i worden gemaakt om de ALs zo efficient en effectief mogelijk te alloceren.

Q5.1: Als laatste vraag zijn er een aantal aannames die gemaakt zijn die ik graag met u bespreek. Klopt het dat voor en score van Tis 1.2 en hoger een AL uitrukt.

> **A5.1:** Voor een Tis score van 1,2 en hoger worden we eigenlijk altijd opgeroepen. Ook voor een Tis score van 1.1 wordt er vaak van ons verwacht dat we optreden.

Q5.2: En hoe lang werkt een AL maximaal aan een Incident?:

> **A5.2:** Als een incident lang duurt, rond de 10 tot 20 uur, dan is er vaak constant een AL betrokken. Er wordt dan een extra AL geregeld en ingezet om deze zaak over te nemen. Een AL die volgens het rooster is ingedeeld zal er naar schatting maximaal 5 uur zijn.

Appendix E - Overview ProRail