Effectiveness of static detour signage on motorways

MSc Transport, Infrastructure and Logistics

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Effectiveness of static detour signage on motorways

by

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Preface

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Executive Summary

Dutch motorways are subject to both planned and unplanned road works to maintain quality and ensure smooth traffic flow. These roadworks emphasise the need for effective traffic control measures to improve safety and minimise disruption. In the Netherlands, static traffic signs are the main form of communication for road users during motorway road works. These signs provide essential information about road works, closures, traffic changes and alternative routes. However, the placement of static signs poses notable safety risks to road workers. Despite their widespread use, there remains a gap in research into the impact of static traffic signs on driver behaviour and route choices. Addressing this gap is important for improving the effectiveness of traffic control measures and the safety of road users and road workers during road closures. This study aims to fill this gap by answering the following research question:

What is the influence of static traffic signs on motorways on drivers' route choices and driving behaviour on following a detour?

The research question will be investigated through the development of a theoretical framework of detour behaviour and two observation studies conducted near motorway closures in the Netherlands. By analysing real-time travel behaviour and route choice, the research aims to provide insight into the effectiveness of static traffic signs and their role in managing traffic around road closures and diversions.

A road closure near the motorway, accompanied by a detour, presents road users with a number of decisions to consider when approaching this location. The primary decision is whether or not to follow the suggested detour. The decision not to follow the detour could involve either choosing an alternative route or continuing towards the closed road despite the traffic measures in place. In addition, road users can decide to avoid the road closure altogether, influenced by pre-announcement information displayed at the closure location up to two weeks in advance. Detour behaviour reflects a complex interplay of psychosocial, contextual and economic factors. All of these factors influence the driver's decision on route choice and driving behaviour. The interactions between these factors are important to capture the complex decision-making process of drivers in detour situations. In addition, the driving behaviour of road users is influenced by these factors and is characterised by their driving style. Therefore, the four categories of driving styles that can be encountered around a detour are Careless, Fearful, Skilled and Patient Driving. The combined effect of decision-making and driving behaviour around detours leads to the identification of four driver profiles that capture the complex dynamics of this interaction. These profiles correspond to the main decisions made by road users: to follow the detour, not to follow the detour, to choose an alternative route, or to avoid the detour location. Each profile is associated with potential driving styles, providing insights into the different behaviours associated with detour decisions. Considering the interaction of these factors and decision-making, a number of scenarios are developed around road closures and associated detours. These scenarios capture the diverse responses of road users to detours and provide a comprehensive understanding of detour behaviour. The integration of different aspects of the decision-making process and driving behaviour around road closures results in a systematic conceptual framework that captures the complex dynamics and provides a comprehensive understanding of the different occurring scenarios. The developed detour behaviour model, illustrated in Figure 1, demonstrates the interaction between factors influencing route choice and associated driver profiles by outlining different scenarios across the stages associated with a road closure.

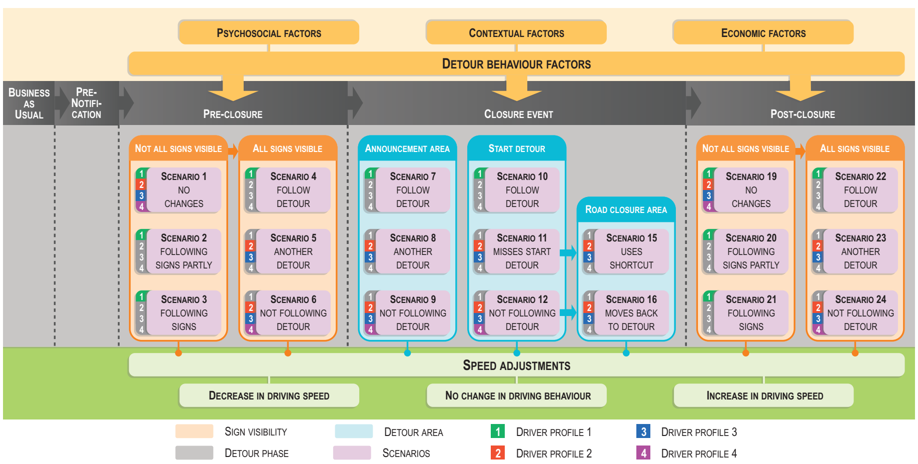

Figure 1: Detour Behaviour Model

Two observation studies have been performed to investigate the impact of static traffic measures during road closures. These case studies examined route choice and average speed on the motorway around the closures, focusing on the closure of an access road next to motorway exit ramps during the night hours. The analysis of motorway behaviour was based on traffic volume and average speed data derived from detection loop recordings. Route choice around the closures was investigated using Automatic Number Plate Recognition (ANPR) camera measurements.

In the case study, which focused on the closure of the Schipholweg near exit 9 Aalsmeer of the A9 motorway, route choice was evaluated using two ANPR cameras positioned on the exit and access ramps near the Schipholweg. These cameras observed vehicles using the exit and returning to the motorway within two minutes. The results showed that a significant proportion of road users deviated from the expected route, as indicated by the number of vehicles that turned at the roundabout due to the closure of the Schipholweg. Specifically, this deviation accounted for 18.3% of the expected number of vehicles on the exit ramp. A further breakdown by the number of vehicles from this group that were expected to head for the Schipholweg showed that 73.8% of these vehicles did not follow the diversion signs. The remaining traffic either continued past the exit to follow the detour or chose an alternative route. No significant differences in driving behaviour were observed on the motorway around the static traffic signs and the exit ramp. The case study conducted around the closure of the Hagenweg towards Vianen near exit 27 Hagestein of the A27 motorway investigated a more detailed route choice analysis. By studying vehicles using the exit near the closed road, the shortcut and the detour using ANPR cameras, a more detailed analysis of road users' route choice is performed. The results showed that only 32% of road users respected the traffic control measures by following the detour. A significant proportion of 60% of road users disregarded the measure by taking the Hagestein exit to head towards the shortcut. However, a small percentage of 4% initially did not follow the diversion but later returned to the motorway to follow it, while a further 4% chose to avoid the closed road area completely. Similar to the findings on the A9 motorway, no significant differences in motorway driving behaviour were observed.

The developed detour behaviour model is evaluated using the revealed preference studies, showing the presence of the four different driver profiles in the real world and therefore indicating the possible scenarios around a road closure. Driver profile 1 is characterised by the decision to follow the detour. In the two case studies, this profile is found in a range from 26.2% and 36%. Meanwhile, Driver Profile 2, representing those who are not complying with the detour, accounts for between 64% and 73.8%, partially overlapping with Driver Profile 3, where drivers choose an alternative route, such as a shortcut. In addition, the fourth driver profile makes a small contribution (4%), consisting of drivers who take the closure information into account and avoid the area. The results of this study show that between 64% and 73.8% of road users disregard diversion information by deciding not to follow the indicated diversion. These results emphasise the complexity of driver behaviour around road closures and demonstrate the limited impact of temporary static road signs in diverting road users around road closures. The absence of significant deviations in driver speed on the motorway around the static traffic signs further supports this conclusion by showing limited changes in driver behaviour.

The development of the Detour Behaviour Model, which systematically captures drivers' responses and route choices by four different driver profiles, represents a step forward in the current literature by providing a deeper understanding of detour decision-making and driving behaviour. In addition, this research fills a gap in the literature by investigating the influence of static temporary traffic control measures, providing empirical insights into the real-world dynamics of driver behaviour. Moreover, the findings of this study provide practical insights into the different responses of road users and the different scenarios surrounding road closures and diversions. The empirical results emphasise the urgent need for improved signage strategies and communication methods during road closures, especially considering the significant number of drivers who disregard diversion signs.

This study uses two case studies to investigate road user behaviour during road closures. However, it has several limitations that affect the interpretation of the results. The focus on closures within the secondary network limits the ability to generalise the findings to other closure scenarios, while the narrow time frame may not fully capture broader traffic patterns. Data limitations prevent analysis at the individual level, limiting the depth of understanding of individual driver behaviour. In addition, while the Detour Behaviour Model provides valuable insights into motorway detours, certain components remain untested, such as the correlation between factors and the scenarios, despite being validated by experts in detour and traffic control measures and the findings of the case studies. These untested components create gaps in the understanding of specific decision characteristics and their interactions with various factors. Addressing these limitations is essential to improve the comprehensiveness and applicability of the model. Despite these limitations, this research improves the understanding of road users' route choices around detours. The Detour Behaviour Model provides guidance on drivers' route choices, and the case studies showed actual route choices and the limited impact of static detour signage. As a result, the research provides information on current traffic management strategies and their limitations in relation to road closures.

Future research could contribute by addressing the limitations of this research. The detour behaviour model could be further evaluated in the components not tested in this research. Further research into the decision-making process and its correlation with various factors can improve the ability of the model to provide a detailed overview of the complex dynamics surrounding road closures and diversions. In addition, future research should investigate the impact of temporary traffic measures on motorway behaviour at the individual level and by different road closure conditions. Another area of interest is investigating the safety implications of non-compliance and assessing the effectiveness of different traffic management strategies, including the role of navigation systems. Furthermore, the exploration of road closures and diversions in urban areas is of relevance for the development of context-specific management strategies and the understanding of driver behaviour in different environments. Addressing these areas in future research will improve the understanding of road closure dynamics and enable the development of more effective and personalised management strategies.

The observed low compliance rate has practical implications, requiring adjustments to current traffic management systems to direct more drivers to diversion routes. This research was motivated by several accidents involving road workers installing diversion signs. This emphasises the need to review and improve sign placement strategies to ensure the safe diversion of all traffic around roadworks and the safety of road workers installing the signs. Given the low compliance with static diversion signs and the high risks associated with their placement, it is recommended to explore and implement alternative methods of traffic control. This could include the use of dynamic, real-time information, such as smart traffic systems and mobile applications, to guide road users more effectively and improve the safety of road workers. By focusing on road user route choice through the Detour Behaviour Model, proactive measures can be developed, ensuring that traffic management strategies are more closely aligned with actual route choices.

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Nomenclature

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Abbreviations	Definitions
ANPR	Automatic Number Plate Recognition
CROW	Centrum voor Regelgeving en Onderzoek in de Grond- Water- en Wegenbouw en de Verkeerstechniek
VMS	Variable Message Signs
DMS	Dynamic Message Signs
TTC	Temporary Traffic Control
DSD	Dynamic Speed Displays
TCB	Traffic Condition Based
ATIS	Advanced Travel Information Systems
AWIS	Automated Work Zone Information Systems
GRIP	Graphic Route Information Panels
GPS	Global Positioning System
MDSI	Multi-dimensional Driving Style Inventory
PCA	Principal Component Analysis
ADAS	Advanced Driver Assistance Systems
SEM	Structural Equation Model
AADT	Average Annual Daily Traffic
KPIs	Key Performance Indicators

1 Introduction

Dutch motorways are experiencing an increase in the number of vehicles. Every year, the number of kilometers travelled on the motorways increases [109]. To keep traffic flowing as smoothly as possible, work is carried out on the motorways on a regular basis. This includes maintenance, repairs and increasing motorway capacity. Roadworks create disruptions in traffic flow and change the normal situation on the roads. Therefore, roadworks are a major challenge for both traffic management and safety, as maintenance or reconstruction activities affect traffic flow. Closing or narrowing lanes is often necessary to provide a safe working environment for roadworks teams [118]. Implementing effective control measures is essential to mitigate the impact of roadworks on traffic flow. Commonly applied measures include reducing speed limits, implementing lane closures and establishing diversions. These measures not only affect the road network at the construction zone but also have an impact on the surrounding area. Construction zones are some of the most difficult workplaces, with major workplace safety challenges for workers and impacts on the safety and daily commutes of motorists [89]. The choice of control measures directly influences the level of disruption and changes the travel behaviour of motorists [148].

Changes in traffic conditions can be communicated to road users through a variety of different methods, including static road signs, variable message signs (VMS), radio, project websites and public service announcements on television [75]. In the Netherlands, static traffic signs are the main source of information for road users during road works on and around motorways. The static traffic signs used for temporary situations provide information about road works, road closures, additional changes to the traffic situation and relevant detours. The use of detour signage is intended not only to divert traffic away from construction zones, but also to reduce potential risks and prevent accidents [21]. Although control measures are designed to ensure the safety of road workers, there are still many cases where this has not been achieved.

In the Netherlands, the most common accidents around work zones involve arrow trucks and botsabsorbers just outside the work zone [35]. If a car collides with such a truck, warning and information signs may have been ignored or not seen for several kilometres. In the event of a lane closure, warning signs will indicate well in advance that vehicles should reduce speed. Next, arrows indicate that a lane is been cleared from traffic, followed by red crosses indicating that the lane is closed [35]. On average, there are 25 accidents registered per year in which a car driver collides with one of the two vehicles. In 2017, this number increased to 29 and in 2021, 31 incidents had already been recorded by November. Accidents occur not only with the two trucks mentioned but also with service vehicles or other traffic measures. Rijkswaterstaat also recorded 258 close calls in the work zone area [127]. Drivers who ignore the red crosses on the closed lanes are also recorded, resulting in more than 4,500 fines in the first nine months of 2021 [94].

Recently on 24 March 2024, Hooft [50] of Omroep Brabant, published an article calling for the motorway to be completely closed during the construction work and for everyone to be diverted via other roads. Besides measurements showing that 85% of road users drive are speeding along roadworks, the aggressive behaviour of road users towards road workers is another reason for this call [50]. On 23 March 2024, a road worker received a concussion from a bottle thrown at his head from a passing vehicle [95].

These accidents occur despite the many traffic control measures in place around the work zone. However, work is also being carried out where additional measures have not yet been put in place. These include the installation of traffic signs for the upcoming roadworks. In September 2023, there was an alarm call from the road workers installing the traffic signs that something needed to be done about their safety [61]. It was a result of several accidents in which the road workers were not involved but were not responsible. The report followed an accident in which a lorry collided with a work vehicle, injuring the road worker. In an interview conducted by Kamp and Hooft [61], it emerges that this kind of accident happens almost every month. This results in that the road workers ensure safety, but at the same time, they are exposed to danger.

In this interview, it is suggested that placing fewer traffic signs could be a start to solving the problem [61]. However, there has been no research into the possibility of using fewer signs. There have been several studies on the effectiveness of traffic control measures and safety in work zones, looking at the contribution of variable message signs. However, relatively few studies are available on the effectiveness of static traffic signs in providing information about upcoming works and traffic impacts. In cases where a diversion is in place, this is also indicated by static traffic signs. As a result of recent accidents involving road workers at risk and the lack of research into the influence of static message signs on the behaviour of road users, this study aims to determine the influence of temporary message signs on road user route choices and driving behaviour around road closures and associated diversions.

1.1 Research gap and aim

Understanding the effectiveness and operation of traffic control measures is important to ensure the safety of traffic around road closures and road works, as well as the safety of road workers. Despite extensive research into various traffic control measures and diversion planning tools, the specific impact and role of static traffic signs in diverting traffic remains relatively unknown. In this context, static signs refer to 'yellow' signs with fixed black text placed along the road to indicate diversions, road works, road closures or other related information. While recent research has focused on how new technologies can improve road safety, such as dynamic message signs and real-time travel information systems, static traffic signs remain one of the most widely used traffic control measures in the Netherlands to manage traffic. These signs can be divided into permanent and temporary traffic signs [25]. Permanent signs include directional, priority and speed signs, while temporary signs provide information about temporary situations such as road works or diversions.

Despite their extensive deployment, there is a gap in research into the impact of static traffic signs defined in section 3. Most of the existing research is based on simulation studies rather than observational studies of actual driver behaviour. An observation study could provide valuable insights into how drivers respond and how route choices is affected by static traffic signs in the actual driving environment. In addition, by analysing drivers' route choices and driving patterns around road closures and road works, more insight could be gained into the impact of diversions on traffic behaviour.

Therefore, this research aims to investigate the influence of static traffic diversion signs on driver route choice and driving behaviour. To assess the decision-making process of drivers around road closures and associated detours, a Detour Behaviour Model will be developed based on existing literature and expert knowledge gathered through a brainstorming session. This model will be used to provide insights into possible route choice scenarios and driving patterns around road closures. In addition, two observation studies will be conducted near a motorway in the Netherlands to analyse road user decision-making in real-time. This study will focus on investigating drivers' route choices in response to road closures and designated detours by conducting traffic counts. Using the Detour Behaviour Model, the study will identify and analyse drivers' route choices and driving behaviour, providing valuable data on real-time travel patterns and the effectiveness of static traffic diversion signs.

1.2 Research Relevance

Recent accidents related to the installation of road signs for road works show that more attention needs to be paid to improving the working conditions of these road workers. During the installation of traffic signs, the road workers work on the hard shoulder, one metre away from the traffic on the motorway. No other measures are applied to traffic during these road works. In addition, the road workers must be present at least twice at the location of the traffic signs. The number of times they have to be around the sign depends on the time of installation and the type of roadworks. Traffic signs must be installed and removed. In addition, traffic signs can be installed for an extended period of time but not used all the time. This means that the signs are activated and deactivated. In other words, the signs must be visible to the traffic at times when they are in operation and not visible to the traffic at times when the relevant measures are not in operation. This is done differently by different organisations. For example, the signs may be reversed so that the back of the sign is visible to the traffic, or the information may be covered. Different traffic signs need to be placed for each situation, therefore these procedures need to be carried out for each road sign separately.

The road signs indicate the changes in conditions due to the road works and contribute to the safety of road workers in the area of the works. To ensure the safety of road workers in the work zone, it is important to consider the influence of temporary traffic control measures. In addition, it is relevant to the work being carried out on the hard shoulder when the traffic signs are placed that the signs are effective for the traffic. From a scientific point of view, a few different studies have been carried out on variable and dynamic message signs, as well as on proposed diversions, but not on the effect of static message signs placed around the work zone. In addition, most studies of traffic control measures have involved a simulation study, but not the actual driving behaviour of the traveller around the roadworks. Therefore, an interesting area of research is to investigate an observation study on the effect of static traffic signs. The research will therefore contribute scientifically to the understanding of the influence of static temporary traffic control measures on driving behaviour around road closures and associated diversions. In addition, it will provide valuable information on the driving behaviour and route choices of road users.

1.3 Research Objective

In order to provide a clear direction for the aim of this research and to obtain a clear overview of the driver's route choices and driving behaviour around static diversion signs and road closure, the following research objectives were defined for this study:

- Development of a theoretical model of driver decision-making for driving behaviour and route choice in the context of motorway diversions.
- Identify drivers' route choices around static diversion signs during motorway closures using licence plate recognition cameras.
- Investigate whether drivers change their driving behaviour around temporary traffic control measures due to road works or road closures on the motorway.
- Investigate whether an observation study using number plate recognition cameras and detection loops on the motorway could assess the influence of static traffic signs and route choice on the gathering of information relevant to the research.

1.4 Research Questions

Acknowledging the previously mentioned research gaps and objectives, the aim of this research is to identify drivers' route choices and driving behaviour regarding static traffic signs around work zones and associated detours. The following main research question addresses the goal of this research:

Main question:
What is the influence of static traffic signs on motorways on drivers' route choices and driving behaviour on following a detour?

To fully answer this main research question, sub-questions have been formulated. These sub-questions will serve as a guide to finding the answer to the main question. In order to provide a reasoned answer to the main question, a theoretical systematic framework of road user detour route choices and driving behaviour will help to address the complex dynamics of detour responses and driving patterns observed around road closures and associated detours. The defined sub-questions are as follows:

Sub-questions:

1. What kind of model can be designed to demonstrate the response of road users to detours?
2. What driving behaviour can be observed around motorway detours?
3. To what extent do road users follow up the static traffic signs?

The developed sub-questions serve to support the systematic answering of the main research question. Firstly, based on the first sub-question, a model will be developed that addresses the different aspects that influence a road user's choices when approaching a road closure and associated detours. This model should give a more detailed insight into the situations that can occur around the traffic control measures in place during a diversion, and therefore give a more comprehensive understanding of the choices that the road user can make. Then, using two observation studies and the established model, answers will be found to the second sub-question, which looks at the behaviour of road users during a diversion and road closure. This will include driving behaviour in terms of speed adjustments around static traffic signs and route choices. As a result of the analysis of the different route choices, it will be possible to determine the extent to which the traffic signs indicating the measures around the closure are followed up by the road users, which will answer sub-question 3. By comparing the results of the two observation studies with the established model, it is possible to answer the question of how static traffic signs on motorways affect the decision of road users to follow a detour.

1.5 Research Scope

Roadworks occur on all types of roads, including associated traffic control measures. The focus of this study is on traffic control measures on motorways. The reason for this is that the impact of accidents is much greater on motorways, and it is also more difficult to ensure safety because of the higher speeds involved. The traffic control measures considered in this research are static temporary traffic signs announcing roadworks or road closures around the motorway network and the associated diversions. Two case studies are selected to perform observations to investigate the influence of temporary traffic control signs by analysing drivers' decisions regarding diversions and traffic signs. To ensure the feasibility of the observation study, two case study locations in the Netherlands are selected. Therefore, the Dutch traffic regulations are considered in the analysis.

The study is based on case study locations where traffic flows around a closure and associated diversions are analysed. For the research to be feasible, the case study locations must meet certain requirements. The first requirement is to ensure traffic safety. No unsafe situations were allowed to develop around the roadworks. For this reason, it was decided to analyse the closure of an access road immediately after the motorway exit on the secondary road network. In this study, the secondary road network includes the roads located after taking the motorway exit. In addition, in order not to create unsafe situations for vehicles that do not comply with the measures, a location was chosen where a roundabout provides the connection between the motorway exit and the access road. The roundabout allows traffic to safely choose an alternative route. Secondly, the number of available shortcuts should be limited to ensure the feasibility of the range of traffic flows around the road closure. Traffic flows around the closure are analysed using automatic number plate recognition (ANPR) camera measurements. Four cameras are available for the study. Therefore, the case study location must have a maximum of one alternative shortcut.

Static traffic signs are fixed message displays, and in the case of this study, the signs are yellow with black lettering. The term static refers to the fact that the signs are in a fixed location and cannot change the information at different times. This study focuses on the static traffic signs placed by roadworks or road closures on the motorway. Both case studies involve a road closure on the secondary motorway network and include full closure. The closed road is an access road located immediately after the motorway exit. As the access road is immediately after the motorway exit, the closure should be indicated on the motorway to minimise traffic disruption. To minimise further traffic disruption, work and road closures will be carried out during the evening and night hours.

1.6 Research Outline

This research is structured as follows, Table 2. Chapter 2 discusses the methods used in this research, brainstorming and observation studies, to answer the research questions. Chapter 3 reviews existing research on traffic control measures and driver behaviour. In the following chapter, chapter 4, the findings from the literature review and the brainstorming session are used to develop a systematic theoretical framework of detour behaviour. The following two chapters, chapters 5 and 6, discuss the results of the two case studies. Chapter 5 discusses the results of the A9 case study and Chapter 6 the results of the A27 case study. In Chapter 7, the results from both case studies are used to evaluate the diversion behaviour model developed in Chapter 3. Chapter 8 provides a data validation of the data used in the case studies. Chapter 9 discusses the findings of the research. Finally, Chapter 10 concludes the research. This chapter also provides recommendations for practice and future research.

Table 2: Research outline

Chapter	**Outline**	**Research Question**
Chapter 1	Introduction	
Chapter 2	Methodology	
Chapter 3	Literature review	
Chapter 4	Design of Detour Behaviour Model	SRQ 1
Chapter 5	Results Case study A9	SRQ 2 and 3
Chapter 6	Results Case study A27	SRQ 2 and 3
Chapter 7	Evaluation Detour Behaviour Model	SRQ 1, 2 and 3
Chapter 8	Data validation	
Chapter 9	Discussion	Main RQ
Chapter 10	Conclusion and recommendations	Main RQ

2 Methodology

This chapter outlines the methodology used in this study to address the research objective. Firstly, it discusses the motivations behind the choice of methods for this study and the considerations involved. It then details the methods used, including the literature review, the brainstorm session, the observation studies and the corresponding statistical analysis. It also discusses the data available and the essential preparations required for the observations.

2.1 Selection research approach

Relevant research investigating the effectiveness of traffic measures and driver behaviour, and the methodologies used were reviewed to determine the most appropriate research strategy for assessing the impact of static traffic signs on motorway traffic and driver decision-making following a detour. The relevant studies and methodologies used are detailed in Table 58 in Appendix A. Common research methods include literature review, simulation analysis, stated preference surveys, interviews and revealed preference studies. As a case study for their research, several studies have focused on selected locations. A case study is a research strategy that provides a systematic way of obtaining detailed knowledge about a particular situation, event or context [99]. This approach enables the investigation of challenging questions, often focusing on a specific situation or phenomenon in a particular setting.

As the proposed methods are not self-contained, it is important to use a combination of methods to achieve the intended research objective. The advantage of observational studies is that they examine real-life scenarios and provide insights into participants' decision-making without the uncertainties of hypothetical scenarios. It provides an understanding of how people behave in real situations. However, measuring driver awareness is challenging and replicating identical situations is very difficult [1]. Simulation studies, on the other hand, allow accurate replication of scenarios, but may not fully capture the complexity of the real world. While they provide insight into sensitivity to risky situations without exposing participants to danger, their results may not perfectly reflect real-world behaviour [100]. Stated preference studies explore participants' behaviour and preferences by offering a wide range of response options to indicate preferences [141]. However, they do not always reflect actual behaviour and data interpretation can be complex due to theoretical scenarios. However, surveys can provide valuable insights into participants' opinions and behaviours, filling gaps where data is limited or providing complementary analysis. It is possible to conduct a stated preference study of the participants in the simulation study, resulting in a combination of the choices made when performing certain actions and the trade-offs made. A literature review complements all methods by providing a broader understanding of the subject. In addition, data analysis is incorporated into research methods in order to derive meaningful results and draw relevant conclusions, which are reviewed if the results differ significantly from the expected hypothesis of the analysis.

Interviews provide a way of gaining additional insight into specific situations or topics. It is the most common form of data collection in qualitative research, conducted within a structured framework [56]. Through interviews, researchers can systematically explore different aspects of the topic, allowing for in-depth understanding and multi-dimensional perspectives to be gained. Brainstorming is another useful method for generating additional information, ideas or solutions [144]. By following a structured framework, brainstorming facilitates the generation of diverse insights within a specific context. Participants participate in an open and creative exchange of ideas, contributing their perspectives and suggestions to address the topic at hand. This collaborative approach encourages innovative thinking and can generate a range of potential solutions or requirements specific to the situation being addressed.

As a result of the comparison and the use of different methods, it was decided to use the research approach consisting of the following methods including a case study as research location:

- Literature study
- Brainstorming
- Observation study
- Statistical analysis

The choice of this research approach was based on the recognition that the findings obtained from the literature review are key to understanding driving behaviour and decision-making regarding road closures and traffic management measures. In addition, the decision to use a brainstorming session rather than interviews was considered to capture a wider range of driving behaviours and factors influencing driver behaviour. This decision was based on the fact that a brainstorming session encourages active participation and the generation of ideas from different perspectives, which enables a comprehensive representation of the range of driving behaviours on Dutch roads during diversions and closures.

In order to validate the results in real scenarios involving diversions and traffic management measures, an observation study was conducted. This methodology allows the examination of actual behaviour in response to diversions and traffic management measures in real-world conditions. In order to provide a comparative analysis, two case studies were conducted to improve the understanding by identifying recurring patterns rather than isolated incidents. The selection of two different case studies allows for a comprehensive exploration of diversion situations and facilitates a nuanced understanding of the observed behaviours. The first case study focuses on the primary decision-making process regarding compliance with diversion instructions. In the second, the analysis is extended to examine in more detail the route selection process.

The results of the above methods were examined using data analysis. In order to draw conclusions, Chi-square statistical analysis was used to compare the results with expected scenarios. Chi-square analysis was chosen for its ability to calculate the disparity between observed and expected frequencies within categories, thereby assessing the statistical significance of any differences. By comparing the observed frequencies with those expected under a null hypothesis, this method makes it possible to determine whether there is evidence to reject the null hypothesis and confirm the presence of a significant association between variables.

2.2 Literature study

This research conducted a comprehensive review of the existing literature on traffic control measures, route choice behaviour and driving behaviour. The purpose of this review was to gain an understanding of driver behaviour on motorways and around road closures and the factors that influence this behaviour. In addition, this literature review was used to gain a better overview of the existing research on the effectiveness of different traffic control measures and the research methods used to gain insight into this type of research project and therefore aimed to identify the main concepts, theories and methodologies relevant to the study.

The literature review was carried out in two phases. The first phase took place during the writing of the research proposal where the research gap was identified and focused on traffic response to different traffic control measures. At the initial stage of the research, the literature was further reviewed to gain a more detailed understanding of the factors involved in driver behaviour and its influence on route choice.

The literature review was carried out using Scopus and Google Scholar. The research papers reviewed were found using various keywords and their synonyms to obtain a collection of papers. In order to assess the relevance of these documents, their abstracts are carefully reviewed. This is followed by the snowballing strategy, which involves the analysis of references and citations in the identified papers. The papers which have been reviewed are based on the keyword(s) used to search, as indicated below:

Diversion AND Route AND Choice, ”Drivers Behaviour AND (Diversion OR Detour), (Motorway OR Highway) AND (Diversion OR Detour), ”Traffic Control Measures” AND ”Work zone”, ”Navigation systems” AND ”Travel Behaviour”, ”Traffic signs” AND ”Travel Behaviour”, ”Traffic signs” AND (Diversion OR Detour), ”Revealed Preference” AND ”Drivers Behaviour” and ”Revealed preferences” AND (Diversion OR Detour).

The articles found using the search terms were evaluated according to several criteria:

- Concerning traffic on or around motorways.
- Detours are indicated on the motorway.
- Travel behaviour and driving behaviour based on traffic on or around the motorway or diversions.
- Traffic control measures apply to motorways.

Finally, based on the search terms and snowballing strategy for additional relevant research, a total of 81 papers were analysed to map the current state of traffic measures around diversions and motorway closures. and driver behaviour in relation to different measures and navigation systems, and associated factors. The information obtained from the literature was used to represent a conceptual model of road use behaviour around diversions.

2.3 Brainstorm session

In addition to the literature study, a brainstorming session is organised. This brainstorming session was used to gain additional insight into behaviour around traffic measures and diversions, with a focus on static traffic signs. Static traffic signs are not well represented in current studies, so this brainstorming session provides additional insights that can be used to better incorporate behaviour and decisions around diversions.

Several experts from Traffic & More were invited to the brainstorming session. Traffic & More is a company that specialises in temporary traffic measurements for infrastructure projects and road works in the Netherlands. These experts work in different phases of the process for traffic measures around closure, and the participants also regularly use the motorway themselves and are therefore familiar with the traffic situation in the Netherlands. Five employees were invited to the brainstorming session. Two of them work in the company's engineering department. They design traffic measures for motorways and other road closures. This involves determining where the measures, such as traffic signs, should be placed. This includes deciding which traffic sign to place and what information to include. A work planner was also invited to the brainstorming session. The work planner deals with the application of the measures and ensures that all the traffic signs are ready for installation. An executor is also involved in the brainstorming session. The executor is responsible for ensuring that the traffic measures are temporary and that everything goes well during the measures. This gives the executor additional insight into what happens, for example, during a closure or diversion. Finally, a project leader was present. The project manager deals with projects that are implemented over a longer period of time, or where several measures are implemented over a period of time. The project manager can provide additional insight into the progress and impact of traffic measures.

The brainstorming session started with a small introduction of what the research had been and what the planning was going to be for the session. At the start, however, the research was discussed in depth so that the participants went into the session open-minded. They were then told that research was being done on traffic behaviour on motorways. This was done initially so that the first topic could be discussed properly. Namely, this was about the kind of road users encounter on motorways. For this, it was important that they looked at their own experience and knowledge about traffic. Therefore the following questions are discussed:

What different types of road users are there, and how might their needs and behaviours differ?

Next, the session discussed what factors play a role in driver behaviour. First, there was a general discussion of what factors there are, and then a look at what categories these factors belong in. Therefore the following question is used:

What factors influence driver behaviour?

After a short break, the introduction to the study continued. It was explained that the study is about traffic behaviour around static motorway signs indicating a diversion. To do this, the study looks at what choices drivers make using an observation study and whether this shows a difference in behaviour on the motorway. With this information, the brainstorming session moved on to traffic situations around diversions. In order to do this, the previous two questions were first revisited, but now the focus is on what happens around the diversions. This is done with the following two questions:

Which road users can you see around the detour announcement and the detour itself?
What are the factors influencing the decision to follow a detour?

After discussing traffic around static sign diversions and the diversions themselves, there was a short briefing on the research approach and the case studies carried out. Based on the introduction of the case study of the A27 before the Hagenweg closure, the expected scenarios were discussed for different sections of the motorway and for the whole case study area. In doing so, the following questions were addressed for each section:

What is the road user's reaction to the situation and to traffic measures and announcements?
What scenarios could occur at the location?

The brainstorming ended with a discussion of the expected results of the study. The results of the brainstorming session for each question are shown in Appendix C. The brainstorming session provided insights into the behaviour of traffic on the motorway and how this behaviour differs when there is a diversion. In addition, extra insight was gained into situations that may arise around the case study of the A27 and diversion. From this, hypotheses were drawn up, which are discussed in subsection 6.3. To compare the expected results with those found. The main expectation is that there will be limited changes in behaviour on the motorway. It was also taken into account that it is important to include nighttime in the study, as this may be different from daytime when it is light.

2.4 Observation study

In order to gain insight into how road users behave when static traffic signs indicate a diversion, two case studies were conducted to find out the route choices of road users. Both case studies involve the closure of a road in the secondary road network alongside a motorway during the evening and night hours. The following case studies are performed:

1. A9 exit 6 Aalsmeer, closure Schipholweg
2. A27 exit 27 Vianen, closure Hagenweg

The first case study was carried out on the A9 near Schiphol Airport. The case study area includes the motorway section before and after exit 6 (exit Aalsmeer) towards Badhoevedorp on the A9. The road to Schiphol Airport was closed after the exit. The second case study is carried out on the A27 around exit 27 (exit Hagestein). In this case, the road towards Vianen, Hagenweg, was closed after the exit. The two case studies differ in that in the first, the traffic ignores the road signs and takes the exit, only to find that it cannot continue on the road. In this situation, the only way to get to Schiphol Airport is to turn back towards the motorway. In the second case study, the road is also blocked in the direction of Vianen. However, in this situation, it is possible to take a shortcut. For this case study, therefore, ANPR cameras were used to record which routes are chosen by road users, whereas in the first case study, only which vehicles initially ignored the traffic signs were investigated.

The A9 case study was selected because it is an existing Traffic & More project, requiring only an application for camera measurements. In contrast, the A27 case study is not an existing project and requires permission to carry out measurements and to close the road. Details of this process are explained in subsection 2.8. The choice of the A27 location is based on the good relationship between the municipality of Vianen and Traffic & More, which facilitated a quick application process within the research timeframe. In addition, both locations meet the criteria set out in the scope, subsection 1.5. Firstly, they meet the requirement for limited shortcuts available, with no shortcuts beyond the A9 exit and only one for the A27 case study. In addition, the presence of a roundabout between the exit and the closed road ensures traffic safety and smooth flow in both case studies.

2.4.1 Case study A9 exit 6 Aalsmeer

The first case study was carried out to gain an insight into the proportion of road users who follow traffic signs indicating a diversion and showing the detour. The case study was carried out on an existing Traffic & More project, where traffic measures from a long-term project on the A9 motorway are being managed. The A9 motorway runs from the Diemen junction of the A1 motorway through the southwestern part of Amsterdam, Haarlem and Ijmuiden to Alkmaar [110]. Between 2020 and 2027, various road works will be carried out on this motorway to widen the motorway and add lanes between Badhoevedorp and Holendrecht as part of a larger project to widen the Schiphol-Amsterdam-Almere motorway [108]. During the case study, work is being carried out on the Schiphol viaduct extension. This viaduct is located just before exit 6 Aalsmeer. Traffic heading towards Schiphol Airport takes this exit and then passes below the viaduct. Because of the work, the road below the bridge is closed.

The closure situation

To complete the widening of the A9 motorway, some viaducts also need to be extended. One of the viaducts to be widened is the Schiphol Bridge. Additional space is needed to work on the widening of the viaduct so that the construction works can be carried out safely and properly. Therefore, these construction works will cause some disruption along the different segments of the motorway [107]. Due to the situation, exit 6 Aalsmeer will be closed several times to allow the work to be carried out. The work will mainly take place during the evening and night hours to minimise traffic hindrances. Due to road works on the Nieuwemeerdijk, shown in Figure 2, the exit ramp cannot be closed during some nights. As otherwise the Nieuwemeerdijk will be inaccessible. For this reason, the exit will not be closed and the closure will be limited to the road below the viaduct. As a result, the exit ramp road will still be open to traffic, but the exit at the roundabout at the bottom of the exit ramp towards Aalsmeer and Schiphol will be closed and road users will have to turn around at the roundabout to rejoin the motorway if they wish to travel in that direction. However, this closure will be announced on the A9 motorway and a matching diversion will be indicated by static traffic signs.

Figure 2: Roadworks around Exit A9
Blue arrow: Vehicles heading towards Nieuwemeerdijk
Red/white band: Road closure

Traffic control measures
A number of measures have been taken to ensure that traffic disruption is limited. The traffic measures include various static traffic signs informing road users of the announcement and the associated diversion. The traffic measures will follow the guidelines described in subsubsection 4.1.1 and basic plan configuration of Figure 12. The announcement area provides information about the road closure and the associated diversion. The information is displayed to the road users via the static signs shown in Figure 13b. All diversion and traffic management signs and their locations are shown in Figure 79 in Appendix F. The associated detour corresponding to the road closure is shown in Figure 3. The detour involves diverting traffic from the motorway to the A4 via the Badhoevedorp junction to exit 1 Amsterdam-Sloten. From there, vehicles will turn around and rejoin the A4 on the opposite side. At the Badhoevedorp junction, take exit 2 onto the A4 in the direction of Schiphol Airport and then exit 6 onto the A9 in the direction of Aalsmeer. Drivers coming from the Nieuwemeerdijk in the direction of Schiphol or Schipholweg should take the A9 access ramp and follow the same route as the motorway traffic.

Figure 3: A9 Detour associated with road closure Schipholweg
Blue arrow 1: Vehicles heading towards Nieuwemeerdijk
Blue arrow 2: Associated detour with closure Schipholweg
Red/white band: Road closure

The indicated diversion will cause some traffic disruption. The additional average journey time is equal to 6 minutes [42]. In addition, confusion or doubt may arise because the exit ramp remains accessible in this study situation. Drivers may also choose to use the exit and risk reversing, adding at least 1 minute to their journey time [44]. The time measurements of the diversion route are shown in Appendix G. In addition to this diversion, there are two alternative routes. The direction of these alternative routes is shown in Figure 4. The first direction (orange direction) is to continue on the A9 and move towards exit 7 Scheven. This diversion can also be used as an alternative for traffic wishing to take exit 6 on the Schipholweg in the direction of Badhoevedorp. Another alternative is to take the A4, but in the opposite direction (pink direction). In this case, traffic will continue straight on the A9 towards exit 2 at the Badhoevedorp junction onto the A4 towards Rotterdam. Once on the A4, traffic will continue until exit 2 of the A4 towards Schiphol. At this exit, there are two options. Traffic can either take exit 6 onto the A9 or continue to Schiphol. The complete route of the alternative routes are shown in Appendix F.

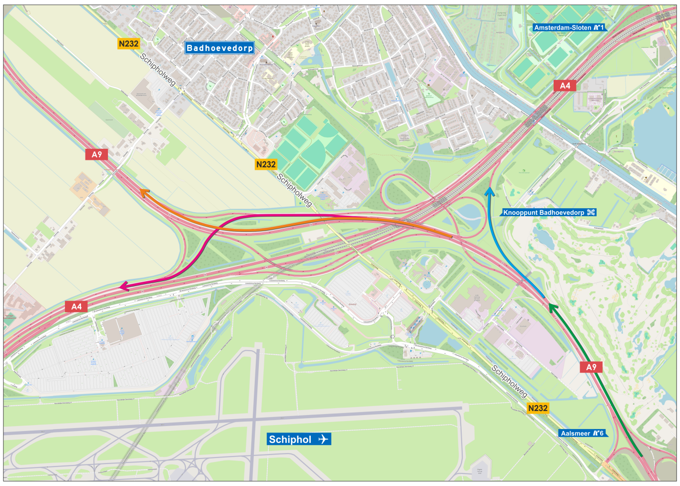

Figure 4: Alternative route directions A9
Blue arrow: Detour direction
Orange arrow: Vehicles in the direction of Badhoevedorp
Pink arrow: Vehicles in the direction of Rotterdam

Study area

The case study uses the partial closure of exit 6 Aalsmeer, shown in Figure 5. The location is suitable for measuring the traffic that does not follow the static traffic signs and the detour route by analysing the traffic on the motorway around the closure and on the associated on- and off-ramps. Traffic on the associated on- and off-ramps is measured by ANPR cameras. These measure the number of vehicles entering and exiting the motorway. In addition, the cameras measure the number of vehicles that have been detected by both cameras within a period of two minutes. Detection loops on the motorway are used to analyse the reaction of the traffic. The detection loops collect data, NDW data, showing the average speed per hour and the traffic volume per hour.

Traffic flows are not the same at all hours of the day and on different days of the week. For this reason, the measurements were taken during work on the Schiphol Bridge. The partial closure of the exit ramp and the road works took place at the following times 06-02-2024 (20:02 - 04:18), 07-02-2024 (20:27 - 03:05), 08-02-2024 (20:28 - 03:05) and 09-02-2024 (20:05 - 01:47). For the traffic evaluation, the closures with the most traffic were selected. This means that the analysis will include traffic around the closure in the evening hours 20:00 - 24:00 on Tuesday (06.02.2024) and Thursday (08.02.2024). Tuesday and Thursday evenings are the busiest days of the week in the Netherlands according to Rijkswaterstaat [106].

ANPR camera measurements

Two ANPR cameras have been installed on the entry and exit ramp of exit 6 Aalsmeer. The cameras measure the number of vehicles per hour seen by the cameras at each station. Using automatic number plate recognition, the cameras are able to detect if a vehicle is seen by more than one camera. By setting a time period between possible detections, combinations of locations can be made, resulting in a route travelled by the specific vehicle. For this case study, the time between a vehicle being detected by both cameras was set to 2 minutes. If the vehicle is first detected by the exit camera, this means that the vehicle came from the motorway and took the exit. If the vehicle is then detected again by the camera installed on the ramp towards the motorway within the time limit, it means that the vehicle has turned at the end of the exit at the roundabout to head back towards the motorway, shown as the pink traffic flow in Figure 6.

Figure 5: Study area A9
– Detection loops
Red/white band: Road closure

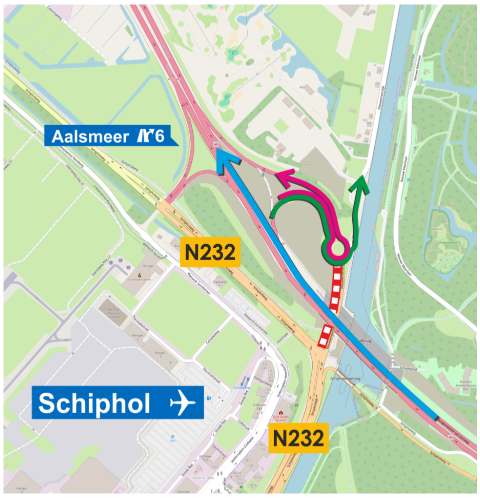

Figure 6: ANPR camera traffic flow detections
Pink arrow: vehicles turned back towards motorway
Green arrow: vehicles towards Nieuwemeerdijk
Blue arrow: vehicles travelling on motorway
Red/white band: Road closure

NDW detection loops
The behaviour of all traffic on the motorway is analysed using NDW data collected from motorway detection loops. The motorway detection loops are located at several points around the exit ramp. The selected detection loops can be seen in Figure 5. The detection loops collect total traffic volume and average speed on the motorway. This information can be used to analyse traffic response to static traffic signs around the closure. The detection loops can also be used to determine the number of vehicles on the ramp. For the exit ramp, the difference in vehicles between HMP 31.2 and HMP 31.6 is used. For the number of vehicles on the ramp, the difference between HMP 31.6 and HMP 32.0 is used. The announcement signs are placed in front of the HMP 30.8 detection loop. The reaction of the traffic to the signs can be analysed by this loop. In addition, the message signs are placed around the detection loop. This allows the loop to visualise the reaction of the traffic to the signs. Around the HMP 31.2 loop, the direction of the diversion is indicated, followed by the exit. The loop can be used to analyse the reaction of traffic to the diversion signs and the approaching exit, which should not be taken if the signs are followed. Diversion signs indicating the right direction were also placed after the exit and ramp. The HMP 32.0 loop can be used to analyse the reaction of traffic to these signs.

2.4.2 Case study A27 exit 27 Hagestein

The second case study was conducted to understand which road users follow static road closure and diversion signs, and which routes these road users choose. The site and closure where the measurements for the case study were taken is not an existing project. The setup for this case study was completely designed for the study. The case study took place around exit 27 Vianen of the A27 motorway in the direction of Almere. The A27 motorway runs from the Sint-Annabosch Breda junction in the direction of the Almere junction [5]. An access road on the secondary road network in the direction of Vianen was closed for the purpose of the study. A diversion route was arranged for this closure and traffic signs were placed to inform road users.

The closure situation
In order to study how traffic behaves around closure and how it reacts to static traffic signs, the access road to Vianen, Hagenweg, was closed on the secondary road network of the A27 motorway. There were a number of requirements for the research location as no actual road works were carried out during the closure. The associated requirements are discussed in subsection 1.5. In addition, the closure and the placement of traffic signs and ANPR cameras had to be approved by the local council, the municipality of Vianen and the Public Works Department of Rijkswaterstaat.

Traffic control measures
In order to close the Hagenweg in the direction of Vianen, multiple traffic measures were required. These measures should at least follow the basic plan configuration of the CROW guidelines described in subsubsection 4.1.1. The measures were introduced by announcing the closure two weeks in advance located at the start of the Hagenweg via a static traffic sign, shown in Figure 7. When the Hagenweg was actually closed, several measures had to be taken. For this purpose, it was

necessary to indicate the closure not only on the motorway, but also on roads in the secondary road network in the area of the closure. Diversion routes were used to ensure the closure was carried out safely and to minimise disruption to traffic. As this study focuses on traffic to and from the motorway, the relevant measures are discussed in detail. The other measures, combined with those from the motorway, can be seen in Appendix J. The measures on the motorway can be divided into different sections: the announcement area and the start of the detours. In the announcement area, there are traffic signs announcing that there is a diversion, the reason for the diversion and how to follow the diversion. Before the detour starts, the announcement area shows which letter or number to follow to navigate the detour, shown in Figure 8.

Figure 7: Pre-announcement sign closure Hagenweg A27

Figure 8: Detour traffic sign A27

Motorists heading towards Vianen are advised to take the diversion, which is shown in Figure 9. The diversion involves passing the original exit 27 towards Vianen and taking the next exit. This is the Nieuwegein exit, where it is necessary to reverse via the Nieuwegein ramp to access the motorway A27 in the direction of Breda to return to the Vianen, and finally take the Exit Hagestein in the opposite direction. This diversion gives an average additional travel time of 4 to 6 minutes [43].

Figure 9: Detour road closure Hagenweg A27
Blue arrow: Detour route

Study area

The study area for the A27 case study covers part of the secondary road network and the A27 motorway, shown in Figure 10. The area considers the section of the motorway where the various traffic signs are installed to inform traffic of the closure and to prevent disruption by diverting traffic around the closure. In addition, it includes the possible routes that vehicles travelling towards Vianen could take to continue their journey. Therefore, the section of the motorway included in the study starts where the first traffic signs are placed and ends at the Nieuwegein exit, as shown in the figure with blue arrows. Furthermore, the area around the closed road is taken into account. This includes the area on the secondary road network of the closure of the Hagenweg, the roundabout between the Hagenweg and the Hagestein exit and the possible detour to Vianen via the Lange Dreef, shown by the orange arrow.

There are three possible traffic flows around the closure due to traffic coming from the motorway in the direction of the (closed) Hagenweg. These include the indicated detour on the motorway as shown in Figure 9. In addition, two alternative traffic flows may occur during the closure of Hagenweg. Therefore, the second route analysed is the shortcut. On this route, traffic heading for Vianen still takes the Hagestein exit, despite the temporary traffic signs. After the exit, the traffic heads towards Lange Dreef to continue to Vianen. Finally, the traffic that initially takes the Hagestein exit turns around at the roundabout to take the detour to the Nieuwegein exit and access ramp. The different routes were analysed using ANPR camera measurements. Measurements were taken on four Tuesday evenings between 20:00 and 04:00, on the nights of 27 February and 28 February, 5 and 6 March, 12 and 13 March, and 19 and 20 March. The Hagenweg is closed from 21:00 until 04:40 in the night of 27 and 28 February and on 12 and 13 March.

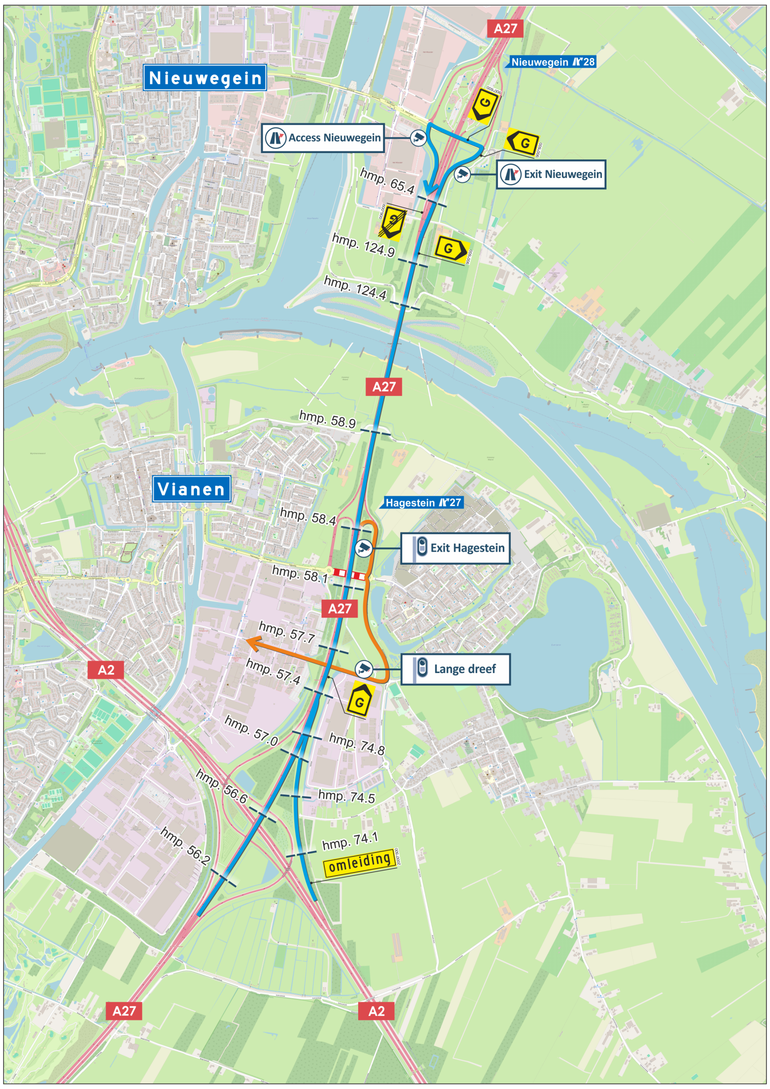

Figure 10: Study Area A27
–: Detection loops
Blue arrow: Motorway section
Orange arrow: Secondary road network section
Red/white band: Road closure

ANPR camera measurements

Four ANPR cameras were used for the case study and to monitor the traffic routes. These were placed at Afrit Hagestein, Afrit Nieuwegein, Oprit Nieuwegein and Lange Dreef, as shown in Figure 10. For each hourly location, the ANPR cameras count the number of vehicles that have passed that location based on the number plates of the vehicles. In addition, the cameras record the number plates to identify which vehicles have been detected at multiple locations in a given time period. On 19 and 20 March, the ANPR cameras took slightly different measurements than on the other days. On this day, the camera was moved from the Lange Dreef location to the Hagenweg. This was done to make a baseline measurement of the number of vehicles on the Hagenweg and the number of vehicles entering the Hagenweg from the Hagestein exit.

By using number plate recognition, the locations of the vehicles can be linked to the different routes taken around the closure. The routes analysed correspond to the ones discussed previously in the study area. The ANPR cameras' location combinations and corresponding routes are given in Table 3. Route 1 shows the detour route, Route 2 shows the shortcut route and Route 3 shows the traffic that decides to follow the detour route after taking the exit. Route 4 shows the number of vehicles coming from Exit Hagestein towards the Hagenweg.

Table 3: Route detections of ANPR cameras
x : camera installed on location

Route	**ANPR camera Locations**				
	Exit Hagestein	Exit Nieuwegein	Access Nieuwegein	Lange Dreef	Hagenweg
Route 1: Exit Nieuwegein - Access Nieuwegein		x	x		
Route 2: Exit Hagestein - Lange Dreef	x			x	
Route 3: Exit Hagestein - Access Nieuwegein	x	x	x		
Route 4: Exit Hagestein - Hagenweg	x				x

NDW detection loops
Traffic on the motorway was analysed using NDW data retrieved from the detection loops. The detection loops used per section are shown in Figure 10. The data retrieved can be used to determine the hourly traffic volumes and average speed at which traffic on the motorway around the closure was analysed. The number of vehicles on the exit ramps of Hagestein and Nieuwegein can also be determined via these detection loops. The number of vehicles on exit Ramp Hagestein equals the difference in vehicles between detection loops HMP 58.1 and HMP 58.4. The differences between detection loops HMP 124.4 en HMP 65.4 equals the number of vehicles on the exit ramp Nieuwegein.

2.4.3 Data Analysis case studies

Using the data collected from the two case studies on the A9 and A27, various analyses are carried out to determine the behaviour around diversions and closures. There are several stages around a closure period during which traffic responses may differ. The five phases are the business-as-usual phase, the pre-notification phase, the pre-closure phase, the closure phase and the post-closure phase In addition, two different evaluations are performed to determine the detour decision behaviour and the motorway behaviour in response to static temporary traffic signs. Data collected by ANPR cameras is used to analyse diversion behaviour and detection loop data is used to analyse motorway behaviour. The detour decision analysis is performed differently for the A27 case study and the A9 case study. This is because there is no detour information available for the A9 case study. Motorway behaviour analysis is performed for both case studies in the same way.

Motorway observations
When analysing motorway observations, two different types of data are considered: traffic volume and average speed per hour. The analysis is carried out for the different phases. The pre-announcement phase is not included in the A27 case study because the pre-announcement sign placed two weeks in advance is only on the Hagenweg and not on the motorway. The analysis of the behaviour on the motorway for both data sets consists of the same steps, but taking in consideration the other data sets and consists of the following steps:

1. Business-as-usual phase: Motorway traffic volumes or average speed over the years.
2. Motorway observations traffic volumes or average speed pre-announcement, pre-closure, closure and post-closure phase.

Business-as-usual phase: Motorway traffic volumes or average speed over the years
For both data sources, the average values for all detection loops are determined for the months of January, February and

March for the years 2022, 2023 and 2024. In addition, the minimum and maximum values for 2024 were determined during these months. These extreme values were specifically determined for 2024 to compare with the measurements of the observation studies and assess whether these observations fall within one of the extreme situations of that year. The averages found for the three years are compared with each other and with the minimum and maximum values for 2024 to determine what will be used as the reference values of change in the following steps.

Motorway observations traffic volumes or average speed pre-announcement, pre-closure, closure and post-closure phase
For the different phases, the values found on the days measured are compared with the minimum, maximum of the year 2024 value and the reference mean chosen in the previous step. Furthermore, the results were compared with each other and also with the difference between closure and no closure. The values found are then analysed over the motorway covered by the case study. For the case study of the A27, the average speed was also analysed for each section of the motorway. During the brainstorming session, expectations were identified for the different sections of the A27 motorway. Based on these expectations, hypotheses were formulated and compared with the results found.

In addition, traffic volumes at the exits associated with the case study are determined. The figures found were also compared with the average reference value found in the previous analysis step and the minimum and maximum values for 2024. Based on the number of exits, a comparison was made to see if there was a difference in the use of the exit when the road was closed on the secondary road network compared to normal conditions. The term ”normal conditions” refers to when there is no closure.

Route choice observations analysis A27
The analysis is performed for the business-as-usual, pre-closure, closure and post-closure phases. The pre-announcement phase was not included in this analysis as there were no cameras available to be installed on Hagenweg during this period and no change in route choice was expected. All other four phases are treated separately, however, the pre-closure, closure and post-closure phases are all compared with the business-as-usual phase in the analysis to assess the differences. The analysis of diversion decisions consists of the following steps:

1. Business-as-usual phase: general traffic volumes.
2. Changes in traffic volumes pre-closure, closure, post-closure phase.
3. Expected traffic volumes to change routes because of the closure road.
4. Route selection observations pre-closure, closure and post-closure phase.

1. Business-as-usual phase analysis: This analysis looks at the number of vehicles at the ANPR camera locations on days when the road was not closed. These measurements are used to establish a baseline for the number of vehicles during the closure.

2. Changes in traffic volumes pre-closure, closure, post-closure phase: This analysis compares the numbers at ANPR locations without a closure with the values found when the road was closed. The same is done for the values found for the routes taken by the vehicles. By comparing the number of vehicles detected by ANPR cameras at multiple locations.

3. Expected traffic volumes to change routes because of the closure road: To get a complete understanding of how traffic reacts to closure and which routes are chosen as a result, it is necessary to determine how many vehicles have to take an alternative route at that time. In order to estimate the number of vehicles that are expected to come from the motorway and use the road when it is not closed, the method of linear regression has been used.

The method of linear regression is a statistical technique used to model the relationship between one or more independent variables and a dependent variable [135]. Two variables are used to predict the number of vehicles on the road, which means that the multiple linear regression method is used, as described in Equation 1. In this case, the number of vehicles on the Hagestein exit ramp and the Nieuwegein exit ramp are the independent variables and the number of vehicles on the Hagewneg is the dependent variable. The aim is to find a linear relationship between the independent variables and the dependent variable so that predictions can be made about the expected number of vehicles based on the input variables.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_n X_n + \varepsilon \quad (1)$$

Y = dependent variable
X_n = independent variable
β_n = unknown predictor factor

ε = error term

Based on the results of the vehicles detected by the ANPR cameras and the corresponding routes during the closure, the number of vehicles that had to take an alternative route due to the closure is also estimated from this data. The number of vehicles is based on the number of vehicles detected on Route 1 and Route 2. Route 3 is included because it overlaps with Route 1, otherwise, vehicles would be counted twice. Therefore the used equation is Equation 2.

$$Vehicles = \text{Route}_1 + \text{Route}_2 \tag{2}$$

4. Route selection pre-closure, closure and post-closure phase: Based on the previous steps, it is possible to determine which vehicles are taking which route, and which vehicles are following the detour and which are not. There are two situations to consider when determining the percentages of vehicles following the detour and the route taken by the vehicles. There are two situations that need to be considered when determining the percentages of how many vehicles follow the diversion and which route the vehicles take. The first is that more vehicles are measured than expected. The second is that fewer vehicles are detected than expected.

In the first situation, where the number of vehicles is higher than expected, the percentages are the ratio of the number of vehicles measured on the different routes to the total number of vehicles measured. In the second case, the expected number of vehicles determined by the linear regression method is used. The difference between the measured and expected number of vehicles is the number of vehicles that made a different choice. These vehicles may have stayed at home, left later or earlier, or taken a different route. Then the percentages are determined for the measured numbers on the routes or vehicles with a different choice compared to the expected number of vehicles.

Route choice observations analysis A9

For the A9 case study, there is no data available to measure which vehicles use the diversion or which take a different route. Therefore, as for the A27 case study, it is not possible to determine which routes vehicles take to analyse behaviour around diversions. However, information is available on the number of vehicles that took the exit and then failed to continue and returned to the motorway. On the days when the Schipholweg is closed because of construction works, only the road towards Nieuwemeerdijk is open to traffic. However, this route is not a possible shortcut for traffic heading towards the Schipholweg. For this reason, the ANPR cameras installed on the exit and access ramp can be used to determine which vehicles have taken the exit and therefore disregarded the temporary traffic signs. The analysis to determine the proportion of traffic that takes the exit and then has to return to the motorway is made up of the following steps:

1. Change in traffic volume during closure of Schipholweg compared to without closure.
2. Number of vehicles expected on Schipholweg and Aalsmeer exit without closure.
3. Route choice observations during the closure.

1. Change in traffic volume during the closure of Schipholweg compared to without closure: To assess the impact of the temporary measures and the closure, changes in traffic behaviour during the closure and without the closure were measured. This is done using ANPR camera measurements taken on Thursday 1 and 8 February. On 1 February, the Schipholweg will be open to traffic and there will be no construction works, and on 8 February, the road will be closed.

The measurements on 1 February took place between 21:00 and 03:00, and the analysis will be carried out for these hours. First, it will be examined whether more or fewer vehicles use the Aalsmeer exit as a result of the closure, and then it will be compared whether there are any differences in the number of vehicles turning after using the exit.

2. Number of vehicles expected on Schipholweg and Aalsmeer exit without closure: In order to determine the proportion of traffic that uses the exit and then experiences that it is not possible to use this road in the direction of Schipholweg, it is therefore estimated what traffic would use the Schipholweg and exit Aalsmeer on the day in question if there had been no construction work. The Linear regression method, shown in Equation 1, was used to estimate traffic volumes using data from ANPR cameras and NDW detection loops.

The data available from the ANPR cameras was used to gain insight into the route choice of the traffic measured on 1 February without the closure. Using the linear regression method, it is possible to determine what proportion of vehicles coming from the Aalsmeer exit used the Schipholweg and what proportion went in the direction of Nieuwemeerdijk. In this case, the number of vehicles detected at the exit on 1 and 8 February are the independent variables and the dependent variable is the number of vehicles that turned to the motorway on 8 February.

On the day that the Schipholweg is closed, information is available from the ANPR cameras and detection loops on how many vehicles use the exit in these conditions and what proportion of these vehicles turn back to the motorway. However, it is not possible to estimate the traffic that has travelled past the exit, as the temporary signs on the motorway indicate that the road is closed. To estimate the traffic using the exit ramp under normal conditions, without the closure, the detection loop data was used. By using the traffic volume for the exit ramp, detection loop HMP 31.2, as the independent variable and the number of vehicles on the exit ramp, difference between detection loops HMP 31.2 and HMP 31.6, as the dependent variable in the linear regression method. This allows an estimation to be made of how many vehicles would be expected to use the exit ramp on the day in question if there were no closure, considering the volume of traffic on the motorway. This estimate can then be compared with the actual numbers recorded at the Aalsmeer exit on the day in question. Therefore an estimate of the proportion of vehicles that did not use the exit ramp because of the works and the proportion of vehicles that tried to use the Schipholweg can be obtained.

3. Route decision behaviour during the closure: The results of the two previous analyses can be used to determine the proportion of vehicles that failed to take the Schipholweg and the proportion that continued along the exit after seeing the temporary traffic measures. It is not possible to determine the proportion of the second group that followed the navigation or which route was used as a detour using the results collected. For this reason, a distinction is made between the proportion of vehicles that do not follow the information about the temporary measures by trying to take the exit and the proportion of traffic that responds to the traffic guidance information.

2.5 Statistical analysis

A static test was used to evaluate the results of the different analyses. The Chi-square test was used to evaluate the results. The Chi-square test is a statistical test that evaluates the correlation between the observed frequency and the expected frequency. There are three different purposes for which a chi-square test can be applied [132]:

1. **Chi-square goodness of fit test:** This test is used to determine whether the distribution of a single categorical variable matches an expected distribution.

2. **Chi-square independence test:** This test is used to determine whether there is a correlation between two categorical variables. It can be applied when two variables have been measured and it is necessary to test whether the variables are independent of each other or whether there is a correlation.

3. **Chi-square homogeneity test:** This test is used to determine whether the distributions of a single categorical variable differ between multiple independent sets. It is often used to determine whether there are significant differences in the distributions of a variable between different sets of samples.

Results case study route decisions: To evaluate the results of the case studies of the route decisions the Chi-square goodness of fit test is used. This test can determine whether the observed route distribution is significantly different from the expected distribution. Therefore the expected distribution is equal to the situations where all vehicles follow the diversion signs. The chi-square value will be determined with Equation 3.

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i} \tag{3}$$

Where the observed value O_i is equal to the vehicles following a particular route and E_i is the expected value of vehicles following a particular route when a detour is in place.

Results case study motorway behaviour: The chi-square goodness of fit test is also used to evaluate the results of the differences in traffic volume between the different measurement days and the mean. In this case, the mean is the expected value and the measurement is the observed value.

Data validation - ANPR camera versus detection loops: To evaluate the results of the ANPR cameras and detection loops at the exits the Chi-square independence test is used. The Chi-Square Independence Test can be used to determine whether the distributions of the measured values are significantly different from each other and whether there is a correlation between the measurement methods. The chi-square value will be determined with Equation 4.

$$\chi^2 = \sum \frac{(O_{ij} - E_{ij})^2}{E_{ij}} \tag{4}$$

O_{ij} is the observed value for the combined variable and E_{ij} is the expected value assuming independence. The observed value corresponds to the ANPR camera measurements and the expected value corresponds to the detection loop data.

Data validation - Detection loops: The Chi-square test for independence is also used to assess the differences between the detection loop combinations.

The corresponding chi-squared value should be compared with the corresponding critical value to determine if there is a significant correlation between the values. The critical value depends on the probability value chosen as the appropriate significance level. If the calculated chi-squared value is greater than the critical value from the chi-squared distribution for the chosen significance level, this indicates a significant correlation. This indicates a significant difference between the observed and expected values. This means that if there is a statistical result that is less than the chosen probability value, the p-value, there is a significant effect. If the calculated chi-squared value is less than the critical value, the null hypothesis is accepted and it is concluded that there is no significant relationship between the variables.

The critical chi-squared value can be determined by the degrees of freedom, df. The degrees of freedom can be determined using the rows and columns of the corresponding contingency table of the data, shown in Equation 5.

$$df = (rows - 1) \times (columns - 1) \tag{5}$$

For the purpose of this research a probability value of 0.05 is used. Therefore the critical values shown in Table 4 are applicable for this statistical test.

Table 4: Critical chi-sqaured values for P-value 0.05 and 0.01

df	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
P-value 0.05	3.841	5.991	7.815	9.488	11.070	12.592	14.067	15.507
P-value 0.01	6.635	9.210	11.345	13.227	15.086	16.812	18.475	20.090

2.6 Data availability

The ANPR camera and NDW data are used to perform the analyses. Therefore, the different options and the accessibility of the data are discussed.

2.6.1 ANPR cameras

A total of four Traffic & More ANPR cameras will be used in the study. ANPR cameras are in general very accurate at recognising number plates. Factors such as weather conditions, dirt on the number plate, and vehicle speed can affect the accuracy of recognition [97]. The exact accuracy of ANPR cameras cannot be accurately determined due to varying conditions. To maintain the highest possible accuracy, the cameras are monitored at random, unregistered intervals to analyse and correct any deviations. A total of five half-hour sessions are conducted to assess and ensure the accuracy of the ANPR cameras. No false or missed readings are found during these periods.

Camera readings can be retrieved by a mobile operator at the time of measurement. Data is also stored on the camera's SD card. Once the data has been retrieved from the cameras, a script links the duplicate plates to create location combinations for vehicles detected by two or more cameras within a selected time period. Once the data has been retrieved from the data and script, the licence plates are not stored in order to protect the safety of road users. Only the number of vehicles associated with the detection combinations is known. It is important that the data processing is carefully checked for possible errors and that correction mechanisms are built in to correct false plate matches. Scripting and data processing to ensure data reliability is discussed further in subsection 2.7.

2.6.2 NDW data

NDW data contains information from detection loops installed on Dutch motorways. There are two ways to obtain NDW data. Either open data can be used, or more extensive options are available by using NDW's Dexter tool. However, the Dexter tool requires an approval application [91]. The difference between the NDW open data and the dexter tool is mainly that within the dexter tool, there are more options to retrieve your data with more information and that other time periods are possible. In addition, other data on other topics can be used within the dexter tool, but this is beyond the scope of this study. The dexter tool has the availability to real-time information flows for current traffic data and situation reports from the NDW system NCIS [92].

The data available on traffic volume and average motorway speed depends on the detection loops on the motorway and does not always give the same information. In both the Open Tool and the Dexter Tool, the traffic volume per hour and the average speed can be retrieved. However, in the open tool this is only given as a total for this section of the motorway, but the dexter tool differentiates between lanes. In addition, the information retrieved shows the number of minutes measured in the periods and the quality of the data. Some detection loops can also collect data on vehicle categories, but this is not possible for the loops used in the case studies in this research.

The Dexter tool also provides the option to retrieve data for periods other than hourly per detection loop. However, the values for these periods are based on hourly values. The dexter documentation states "Traffic volumes describe the number of vehicles passing a measurement point and are reported in vehicles per hour. Speeds represent the speed of a vehicle in kilometres per hour. Traffic volumes and speeds are measured using point measurements. This means that a vehicle is measured at one point on the road" [93]. In this research, the Dexter tool is used to obtain the motorway data.

2.7 Data preparation

The data retrieved from the NDW and ANPR cameras are not ready for use in this study immediately after collection. The data needs to be checked for errors and prepared for analysis. The steps required for this are discussed in this section.

2.7.1 ANPR cameras

The data from the script based on the measurements from the ANPR cameras was used for the analyses. An origin-destination matrix was generated from the script, showing the total number of vehicles detected by the cameras per hour, and the vehicle numbers detected by multiple cameras. For each camera, it can be seen where a vehicle detected by that camera was detected by another camera within a given time period.

The data does not make a separate distinction for vehicles detected by more than two cameras. In order to avoid double counting of vehicles on overlapping routes and using them for one of the two routes, a check on overlapping routes is necessary. For the pre-defined routes around the closure shown on Table 3, routes 1 and 3 overlap. To avoid double vehicle counts, the number of vehicles detected by the camera at exit Hagestein and then at access Nieuwegein is subtracted from the number of vehicles detected at exit Nieuwegein and access Nieuwegein. This is because the vehicles at exit Hagestein that are heading towards access Nieuwegein will also pass the camera at exit Nieuwegein.

The database will also show double counts of vehicles going from exit Hagestein to exit Nieuwegein and Access Nieuwegein from the camera at exit Hagestein. However, it can also happen that vehicles from exit Hagestein go to exit Nieuwegein, but not to access Nieuwegein. The number of vehicles not going to Nieuwegein access is then the number of vehicles detected at exit Hagestein and exit Nieuwegein minus the number of vehicles at exit Hagestein and access Nieuwegein.

In addition to the possible routes around the detour, there are other routes that are not considered further in the analysis. These routes are discussed during data validation. In addition, a camera may detect a vehicle twice in a short period of time. This can be due to stationary traffic or a slow-moving vehicle. To avoid double counting, the script will remove from the database any number plate that is scanned a second time within 10 seconds at that camera location, the second scan.

2.7.2 NDW data

The data used for motorway analysis comes from the detection loops. Traffic volume and average speed per hour are used via the Dexter tool. This is the same data that can be retrieved using NDW's open tool. In the Dexter tool it is possible to retrieve data for multiple detection loops and multiple time periods and for a longer period. With the open tool this must be done on a daily basis, otherwise an average will be taken over the days.

Data were retrieved for the years 2022, 2023 and 2024 and for the months of January, February and March. For all hours of the day. Total traffic volumes and average speeds per hour were determined for all detection loops and per hour to prepare the data for analysis. To obtain the total hourly traffic volume, the traffic volumes of the different lanes at the loop location were added together. For the average speed, the average speed of the lanes at the detection loop location was taken. If a detection loop has been inactive or has not detected any vehicles for a period of time, this is indicated by -1 in the data. These values are neglected. In some cases, a detection loop is not operational for the entire measurement period. These loops were not included in the analyses. The average values for the specific day of the week were then calculated for the case study specifications. The same was done for the minimum and maximum values in the data set.

2.8 Case study preparation

In order to perform measurements with ANPR cameras on a project, permission must be obtained from the road authority. The road authority can be a variety of organisations, such as the province, the national road authority (Rijkswaterstaat) or the municipality. It is important to apply two months in advance to get permission to use the cameras. Other regulations apply to the use of ANPR cameras. The cameras must have a power supply and be able to be installed in a suitable location where the number plates can be clearly read. Not every location is suitable and this should be assessed before submitting an application. This is because the camera locations must be specified in the application for approval. It should also specify the purpose for which the data will be used, the days and hours it will be used, and it should not interfere with the privacy of road users.

The ANPR cameras are ready for installation once they have been approved by the road authority. However, to position the cameras safely, traffic measures are required. The traffic measures required for camera installation will depend on the location. This may involve closing part of the road for a short period of time or limiting access to the area where the cameras are being installed. Applications for traffic control measures must be made at least 30 days in advance, but are preferable to be submitted at the same time as the application for permission to use cameras.

The case study carried out around the A27 due to the closure of the Hagenweg is not carried out on an existing project. In order to be able to perform this study, additional steps have to be taken. It is not possible to close a road without permission. For this reason, the closure of the Hagenweg for two nights has to be requested from the Roads Authority and the municipality. In this case study, the application was made to Rijkswaterstaat and the municipality of Vianen. As the road is only closed for research purposes and not for road works, the application must be made well in advance. In addition, the purpose had to be clearly described and it had to be shown that it was important to close the road. In order to maximise the chances of approval, a location with a low traffic impact but a substantial number of vehicles to be measured was selected.

In addition to the request to close the Hagenweg, traffic arrangements must be arranged to minimise disruption. Notice must be given two weeks in advance, Figure 7. In addition, diversion and notification signs must be in place during the closure to direct traffic. These signs must be in place and visible to drivers during the closure and removed after the closure. The closure must also be installed and removed by a team. For the A9 case study, these things do not need to be additionally organised for the study because it is on an existing project and these steps are already being carried out due to the construction work. A budget of between €20.000 and €30.000 is required to conduct these studies.

3 Literature Review

The following chapter provides an overview of the existing literature on traffic control measures and their effects on route choice and driving behaviour. The main goal of the literature review is to identify a research gap in existing literature about traffic control behaviour. It also aims to identify different factors that influence decision-making concerning road closures. The findings from the literature review will be used to construct a systematic theoretical framework of driver behaviour in relation to road closures and associated detours in section 4.

Each section provides an assessment of the available literature and knowledge covering work zone safety, types of control measures, driver responses to traffic measures and navigation systems. It also includes a comprehensive review of the literature on driver behaviour and traffic disruption. Finally, the chapter concludes with an overview of the main findings. A total of 81 sources were considered for this review. A detailed overview of the methods used in each source and the main focus of the paper can be found in Table 57 and Table 58 in Appendix A.

3.1 Work Zone Safety and Traffic Control Measures

Several studies have evaluated the effectiveness of temporary traffic control (TTC) measures in motorway work zones to improve safety and traffic flow. Li and Bai [75] used logistic regression and significance level analysis to quantify the effectiveness of various TTC measures, such as flaggers, traffic signs, arrow panels and portable variable message signs. They found that properly installed measures could control speeds and reduce crashes, but that their effectiveness could not be accurately quantified. A major reason for crashes in high work zones is speeding and the speed variances. Therefore, Shahin, Elias, and Toledo [116] further investigates the influence of physical and digital TTCs on safety using driving simulators and linear mixed effects models. Using linear mixed effects models, the study examines the influence of these countermeasures on both speed reduction and standard deviation of speed. The effects of measures such as rumble strips, dynamic speed displays (DSD), variable message signs (VMS), flaggers, and police patrols are evaluated. The findings reveal that digital countermeasures, DSD and VMS, had limited effects on speeds. Furthermore, another driving simulator study is conducted by Md Mahmudur Rahman et al. [84]. They focused on the impact of sign design on driver behaviour and safety. Their simulator studies showed that the sign's frame refresh rate had a significant impact on drivers' initial speed and deceleration, with longer refresh rates resulting in less frequent text changes for greater effectiveness. Furthermore, they identified that the Dynamic Message Signs (DMS) are more effective at night than other signs.

Multiple studies have assessed the performance of the VMS, while further studies have evaluated driver responses to the VMS. The impact of using VMS in various European cities was evaluated by Chatterjee and Mcdonald [17] with the use of traffic measurements and simulation studies. The simulation study assumed that the traffic in the reference case was distributed to an equilibrium state, and for the VMS effectiveness case, that all relevant drivers were the ones who passed the VMS information and intended to proceed to the destination following the VMS route guidance information, resulting in an overall compliance rate of 92%. The simulation study indicates that VMS information typically has minimal impact on travel distance, but it does reduce queues and localized congestion. Furthermore, the stated preference study findings indicate that the VMS information caused route changes in a varying percentage of drivers, which was influenced by the relevance of the information presented. Additionally, Horowitz, Weisser, and Notbohm [52] explored the impact of VMS on driver behaviour and route choice by a case study. They highlighted the effectiveness of VMS in diverting traffic but raised safety concerns about potential driver distraction due to attention demands. Nevertheless, they suggest that a 10% diversion rate during peak periods is achievable if up-to-date information is provided. These findings are supported by Erke, Sagberg, and Hagman [38], who obtained similar results assessing the impact of VMS on driver behaviour. Using VMS led to effective traffic rerouting, although VMS's attentional demands raised safety concerns due to potential driver distraction, however, different text sizes to reduce driver distraction were not considered in the study. Route guidance strategies integrated with VMS systems aim to provide diverse traffic information to road users. Therefore, the Traffic Condition Based (TCB) approach to route guidance has been proposed by He et al. [47] and tested through a macroscopic simulation study for an urban area in Beijing. The macroscopic simulation model used in the study assumes that vehicles move at free-flow speed until they reach the congestion point, and worked well in approximating the optimal user equilibrium of the urban area.

3.2 Driver responses on temporary traffic control measures

The effectiveness of traffic control measures and the decision-making process in response to information provided are the subject of several research projects evaluating travel behaviour in relation to road works and travel information systems such as Advanced Travel Information Systems (ATIS) and VMS. A systematic literature review on driver behaviour during road works was carried out by Silveira et al. [117]. Their analysis showed the importance of understanding how drivers respond to traffic information and how their individual characteristics affect the way they choose their routes. The influence of individual characteristics on driver choices and behaviour was also identified in the research of Dia and Panwai [30]. Using a multi-level approach combining surveys and a neural network agent-based route choice model to investigate driver compliance and route choice decisions in response to VMS information, it was shown that socio-economic characteristics of the traveller, familiarity with network conditions and expectations of travel time improvements above certain delay thresholds are important to consider in route choice decisions.

In another study, Acharya and Mekker [2] showed that message content affects the rate of diversion. The study used VMS message history data from I-15 in the United States. By examining diversion rates, the researchers aimed to identify correlations between message content and driver behaviour during crash incidents. The analysis revealed significant correlations between message content and increases in diversion rates. Variables such as "miles to crash", "crash ahead" (without location and miles to crash), crash location, delay information and lane of the crash were positively correlated with increases in diversion rates. In contrast, the presence of messages such as "use caution", "speed suggestions" and "prepare to stop" were negatively associated with increases in diversion rates. The effect of DMS on drivers approaching a work zone was investigated in a different study. Strawderman, Huang, and Garrison [121] evaluates the effect of sign placement distance and design features on driver speed compliance using a driving simulator study, providing insights into efficient signage methods that improve road safety. The study examines the effects of different sign designs, such as static versus dynamic displays, and the total amount of information displayed. The results show that signs specifically designed to encourage drivers to slow down are more successful when they contain short and clear messages. Dynamic signs, which display a complete message within a single display frame, were found to be more successful in encouraging slower driving. In addition, drivers' eye fixations on work zone signs were studied by Vignali et al. [137] and compared with those on permanent vertical signs along rural roads. The results provide insight into driver behaviour and may have implications for road safety in work zones. During the experiment, participants travelled 27 kilometres on rural roads in northern Italy and encountered 23 small work zones. Using an eye-tracking device connected to a GPS recorder, visual fixations were recorded on both temporary (yellow background) and permanent (white background) vertical signage within the work zones. Within the work zones, drivers looked at both temporary and permanent signage about 40% of the time. Drivers tended to look at single work zone signs more frequently and for longer periods of time compared to multiple sign layouts within work zones.

3.3 Driver responses on real-time traffic information

Travel behaviour and decisions made by the road user are influenced by the availability of information about traffic conditions. More and more information is becoming available to drivers, including real-time traffic information. The combined effect of experience and knowledge on drivers' route choice behaviour was investigated by Ben-Elia, Erev, and Shiftan [10]. Their research showed how drivers with and without knowledge made different decisions, and indicated the need for real-time information to maximise route efficiency. Furthermore, Koller-Matschke, Belzner, and Glas [68] studied how different traffic information sources affect a person's behaviour while choosing a route. The Munich-based study evaluated the effects of different traffic management systems on route choice behaviour using a range of observation methods, including automatic number plate recognition (ANPR), GPS monitoring, interviews, and driving simulations. They investigated the importance of individualized traffic information and the influence of radio traffic services and in-car navigation systems on drivers' choice of routes. Similar research was done by Kattan, Barros, and Saleemi [63], which looked into how travellers responded to the significant disruption caused by the construction of Calgary's West LRT line. The study discusses how travellers respond to ATIS, detours, and real-time traffic reports through the use of a questionnaire. The results showed a shift towards public transport as the preferred mode of travel. It also showed that travellers rely on radio and VMS for traffic information. The study highlighted the importance of providing expected travel times on alternative routes and making information more visually available, such as providing maps, to encourage travellers to choose unfamiliar routes, which could be facilitated by ATIS. Automated Work Zone Information Systems (AWIS) have received attention in addition to ATIS. Researchers, such as Lee and Kim [70] and Lee, Kim, and Harvey [71], have evaluated its efficiency in managing congestion, improving safety and providing real-time information to the travelling public during construction projects. The studies discussed the use of AWIS in urban motorway construction projects, its influence on reducing traffic demand through work zones, and the public response to its implementation. The investigation conducted via two separate California-based case studies demonstrated a positive impact on travellers, finding the information provided by AWIS to be accurate and useful. Approximately 76% of participants were influenced by AWIS in changing their travel behaviour, including travel times, routes and modes.

Traffic management recommendations to influence route choice are also investigated by Ringhand and Vollrath [111]. In order to learn more about the probability of choosing a particular route, the study used a driving simulator and a stated preference study to investigate urban route choice. The results showed an opportunity to improve route guidance approaches by encouraging a particular route and providing reasons for the preferred direction of the system, highlighting the potential for improved route guidance strategies. Additionally, Reinolsmann et al. [103] investigates the effect of displaying delay times versus total travel times as ATIS on VMS and Graphic Route Information Panels (GRIP) on driver route choice. Using a driving simulator and eye-tracking technology, the study found that displaying delay times on GRIP resulted in a higher percentage of drivers choosing alternative routes compared to displaying total travel times on VMS. In addition, survey results showed that stated preferences were consistent with revealed route choices, demonstrating the influence of delay time information on driver decision-making. Another study that addresses the information drivers like to receive during the decision-making process is conducted by Jou et al. [59]. They explored the complexity of drivers' decision-making processes when presented with different types of real-time traffic information on motorways. By analysing travellers' responses and route-switching patterns via a stated preference survey, the researchers aim to validate models that identify the effects of real-time information provision on route choice behaviour. The study shows that the provision of real-time traffic information, especially with guidance and quantitative details, is preferred by motorway travellers. This suggests that such information, particularly displayed on VMS, is more likely to be accepted and acted upon by drivers. Empirical results indicate that the provision of real-time traffic information leads to a more even distribution of traffic between motorways. As a result, this redistribution helps to reduce journey times for motorway users, thereby improving the overall performance of the network.

3.4 Driver responses on navigation systems

Additionally, several researchers are investigating the impact of navigation systems on travel behaviour and real-time diversion control. Even in the early stages of in-vehicle navigation systems, Allen et al. [4] carried out a human driver simulator study to analyse driver route diversion and alternative route selection using in-vehicle navigation systems. Their results demonstrated the impact of navigation system characteristics on drivers' detour behaviour, indicating the potential of systems to help drivers avoid traffic congestion. In the same year, the effectiveness of different in-vehicle navigation systems was investigated using computer simulation modelling. Four types of systems - static map, dynamic map, dynamic route guidance and advanced route guidance - were evaluated by Halati and Boyce [46]. The computer simulation showed that parameters such as motorway diversion rates, turning penalties, initial network conditions, and compatibility factors affect the success and acceptability of navigation systems. Adler [3] conducted a study to investigate the effects of route guidance and traffic information on drivers' route choice behaviour. The aim of the research was to gain insight into how different types of traveller information influence drivers' decision-making and route performance. Therefore a two-factor repeated measures experiment in a driving simulator is conducted to assess the effects of route guidance and traffic information on driver behaviour. Participants were randomly assigned to one of four groups, each of which received different combinations of travel information. The study suggests that the provision of in-vehicle route guidance and navigation information can provide significant short-term benefits to unfamiliar drivers. Participants who used route guidance and/or traffic information experienced shorter journey times than those who relied on a simple map. In further research, Cristea and Delhomme [23] investigated driver acceptance and understanding of in-vehicle traffic information systems using a driving simulator. The study found positive attitudes towards in-car information systems, suggesting that personalised and directly relevant messages influence driver behaviour.

Uang and Hwang [133] examines how in-car navigation systems affect drivers' driving behaviour, focusing on information content and congestion information. The study used a questionnaire and a driving simulator study. The results showed that the design characteristics of electronic maps determine how well they perform compared to paper maps. The size of the map and the amount of congestion information had a significant effect on journey times, with congestion information helping to reduce navigation errors. In addition, their results showed that while providing congestion information improves the quality of route selection and reduces navigation errors, sending too many messages can cause attention overload and reduce driving safety. Other studies support the suggestion that navigation systems have a significant impact on travel behaviour [66] [85]. Knapper et al. [66] found that the implementation of travel technology, specifically navigation services, significantly influences unplanned travel behaviour, leading to an increase in unplanned travel activities. The study used a survey to investigate the impact of navigation services on unplanned stops and activities and found that it resulted in a mismatch between planned decisions and actual behaviour. Similar results are found by Wansink and Ittersum [140] using a used a decision-to-stop framework. Metz [85] identified a lack of available research on the impact of navigation systems on travel behaviour and, therefore, conducted an evaluation via a systematic literature review of current information. The study shows the impact of digital navigation tools on travel behaviour, including the availability of real-time congestion information and optimised route guidance. Digital navigation, therefore, changes road use by speeding up journeys during congestion and increasing network efficiency, but it also diverts traffic, affecting minor roads and reducing the benefits for long-distance travellers.

Leuisnk [73] conducted a study to investigate the use of navigation systems during road works. The research included a model-based investigation of different measures, and the results indicate that encouraging or discouraging the use of navigation systems can lead to negative effects such as increased diversion or concentration of traffic. In addition, the amount of information currently available is insufficient to influence traffic positively through network measures alone. The report concludes that the best result can be achieved by combining navigation systems, DRIPs, and simulated bottlenecks. Hway-liem [55] explores potential positive and negative safety-related impacts of navigation systems, as well as the safety requirements that could be applied to these systems. Navigation systems have the potential to improve road safety by minimising search efforts and detours, but they could also have a negative impact on safety if their operation distracts the driver or if the information provided does not meet the driver's immediate needs. Mitigating detour distances can improve traffic safety, especially on unfamiliar routes. However, survey data indicates that navigation systems may not consistently suggest optimal routes, potentially having a negative impact on traffic safety. However, *Monitor Smart Mobility 2023* [87] highlights the frequency with which drivers use in-vehicle assistance systems. The analysis also suggests that different age groups have different preferences for information sources, highlighting the need for personalised approaches to traffic information. For example, younger drivers (under 35 years old) prefer in-car information.

3.5 Factors influencing driving behaviour

Driving behaviour is influenced by a wide range of factors, from individual characteristics to environmental conditions. Understanding the complex interactions between these factors is important for developing effective traffic management strategies, improving road safety and optimising transport systems. The complexity of driving behaviour cannot be explained by a single type of factor but varies from psychological and driver characteristics to environmental factors.

Traditional transport studies often use route choice models derived from random utility theory, focusing on discrete choice models to describe drivers' decision-making processes [10]. However, Psychological research demonstrates the importance of incorporating realistic behavioural assumptions into route choice models. Ben-Elia, Erev, and Shiftan [10] conducted experimental studies in simulated environments to analyse the relationship between information availability, personal experience and drivers' route choice behaviour. The study showed that the inclusion of real-time information and prior experience with travel time variability has a significant impact on decision-making. Prospect theory applied to route choice behaviour demonstrates complex patterns in decision making and risk perception [28] [27]. The "hot stove effect" is illustrated by Denrell and March [28] and Denrell [27], where route decision makers have reduced risk-taking behaviour as a result of limited feedback. In the context of route choice, Katsikopoulos et al. [62] provides additional validation of the principles of prospect theory by focusing on the importance of risk aversion or preference behaviour in response to variations in travel time. The complex connection between time perspective, risk perception, and risky driving behaviour is explained by Măirean and Diaconu-Gherasim [82]. A total of 263 drivers participated in the study by answering survey questions about their demographics, time perspective, sense of risk, and unsafe driving behaviour. To investigate the connections between time perspective dimensions, risk perception, and dangerous driving behaviour, the researchers applied structural equational modelling. More dangerous driving behaviours were reported by participants with higher levels of concerns and negative past and present time perspectives. In contrast, people who had a positive time perspective showed less dangerous behaviour.

Furthermore, various studies have identified specific driver characteristics and demographic factors that influence driving behaviour. The study of Munion et al. [90] shows that when it comes to gender differences in space navigation, males typically do better than women. Using GPS tracking, the study required candidates to navigate across extensive natural environments in order to locate targets indicated on maps. The researchers found particular wayfinding behaviours, such as longer uninterrupted trips, fewer pauses, and less area returning, as correlates of successful navigation in order to explain the association between gender and performance. In addition, research shows demographic differences in response to real-time traffic information. Male travellers and those with higher incomes are more likely to change their route based on traffic information, while older travellers tend to exhibit more familiar and risk-averse behaviour [59]. Similar results are found by Weng and Meng [142] where younger and male drivers are more likely to take risks. In addition, the study of Zhu, Jiang, and Yamamoto [149] examines the characteristics of older drivers' driving behaviour using GPS trajectory data collected by trip recorders installed in their cars. The analysis was carried out in regard to driving distance, time, speed and dangerous driving incidents. In addition, a linear regression model was used to examine the influence of drivers' driving behaviour and socio-economic variables on their speed. The results indicate that older people prefer to travel shorter distances during the day. However, in contrast to the results of [59], where older travellers tended to be more risk averse, the study of Zhu, Jiang, and Yamamoto [149] showed that they were more likely to be involved in dangerous driving situations. Another factor which is influencing driving behaviour is driving experience. Driver experience plays a long-term role in the driving behaviour change from awareness to automation [16]. Using simulated driving sessions, Charlton and Starkey [16] investigated distracted driving and discovered that experienced drivers showed less variance in speed and lane position, indicating automated driving activities. Experienced drivers, however, have difficulty changing their speed by entering roadworks, but are better at observing risks.

Other driver characteristics that influence driving behaviour are discovered by Steinbakk et al. [120]. The study identified the relationship between personality characteristics and preferred speeds in work zones. Through an online survey platform, 815 drivers from Norway were recruited for the study. The most significant predictor of preferred speed in work zones was found to be the existence of visible roadworks, which significantly decreased drivers' speed preferences. Through attitudes toward speeding and danger perception, personality characteristics such as impulsivity, selfishness, and lack of norms demonstrated weak but statistically significant indirect influences on desired speed. The study shows how speed preferences, environmental circumstances, and personality characteristics interact closely in work zones and driving behaviour. Driving experience also influences the likelihood that people will take the information provided by in-car systems or road signs seriously. They react based on previous detour experiences. Another aspect of driving experience is the fact that older drivers have more route experience than younger people and are therefore more likely to take a route other than the recommended route. The study by Weng and Meng [142] examines the effects of the environment, vehicle characteristics and driver demographics on risky driving in work zones using decision tree analysis. The study identifies bad weather and poor road conditions as significant contributors to risky driving in work zones. Drivers are more likely to engage in risky manoeuvres when visibility is reduced or road surfaces are poor. The number of lanes and access management in work zones also play a role in influencing driver behaviour. Risky driving behaviour varies between single-lane and multi-lane roads, with different factors contributing to different conditions such as daylight and darkness. Another factor is the age of the vehicle, with age emerging as a factor influencing risky driving behaviour.

3.6 Driving style

Driving behaviour consists of two separate components, driving skills and driving style [32]. Driving skills refer to the attitudes and character of the driver, so personality characteristics can make an important difference to driving behaviour. Driving style refers to the way a driver chooses to drive, the driver's individual driving behaviour. Consequently, different drivers have different driving styles [20]. Previous research has examined various relationships between driving style and travel behaviour, personal characteristics, crashes and risky driving behaviour. However, the definition of driving style often varies between studies. Therefore, Sagberg et al. [115] conducted a systematic literature review to define a complete definition of driving style. Despite the differences in definition, most definitions have three key factors in common: first, different people or groups of people have different driving styles. Secondly, a driving style is a familiar approach to driving, which implies a relatively consistent way of driving. Thirdly, most of the criteria suggest that a driver's choices are reflected in their driving style. The framework suggests that driving styles develop through the influence of individual, socio-cultural and technological factors, with an important role for reinforcement. Therefore, the researchers proposed a general definition of driving style as "a habitual way of driving that is characteristic of a driver or group of drivers" [115]. They also clarified the difference between driving style and driving behaviour as follows: "The concept of driving behaviour includes all actions (both overt actions and covert or mental operations) that a driver performs while driving" and "Driving styles are subcategories of driving behaviour that meet the criteria of systematically varying between individual drivers or groups of drivers and also being habitual" [115].

The research of Taubman-Ben-Ari, Mikulincer, and Gillath [130] introduces a conceptual framework, the Multidimensional Driving Style Inventory (MDSI). The conceptual framework is used to explain the relationship between car crashes and driving style. It separates driving skill, which refers to the ability to control the vehicle, and driving style, which reflects habitual driving behaviour and attitudes. First of all, according to Taubman-Ben-Ari, Mikulincer, and Gillath [130] there are four driving styles: Reckless and careless driving, Anxious driving, Angry and hostile driving, and Patient and careful driving. Based on these four main styles, the MDSI was developed. A factor analysis revealed eight main factors, each one reflecting a specific driving style: dissociative, anxious, risky, angry, high-velocity, distress reduction, patient, and careful. Significant correlations were also found between the eight factors and gender, age, driving history and personality measures of self-esteem, need for control and extroversion, and personality variables such as self-esteem, need for control, impulsive sensation seeking and extraversion. Complementing the study of Taubman-Ben-Ari, Mikulincer, and Gillath [130], the researchers Huysduynen et al. [54] used the MDSI framework to find the stable factors to identify driving styles. Using questionnaires, the research found that five of the eight factors are significant. The five factors include Angry Driving, Anxious Driving, Dissociative Driving, Distress Reduction Driving and Carful Driving. However, they combined Risky and Careful driving in the analysis, but ar both a driving style profile. The study recognises that various factors influence driver behaviour, including the driving environment, traffic conditions and personal characteristics. In addition, 24 attributes across the five factors appeared to be characteristics appear to be consistent compared to the 44 elements across the eight factors in the original analysis. The resulting framework is shown in Figure 76 in Appendix B.

The integration of driving simulators with traffic simulation allowed Rong, Mao, and Ma [114] to classify drivers into three different categories: aggressive, conservative and moderate, using cluster analysis. They found that roads with aggressive drivers had high flow rates but low stability, while conservative and moderate drivers showed more stable behaviour but lower maximum flow rates. This classification is consistent with the categories identified by Liu et al. [78], which take into account factors such as vehicle speed and acceleration using Principal Component Analysis (PCA), the Fuzzy C-Means (FCM) clustering technique. Based on vehicle acceleration, Sun et al. [124] classified drivers' driving styles into three categories: steady, general and radical. The classification is used to improve the performance and acceptance of Advanced Driver Assistance Systems (ADAS), increasing the potential for integrating ADAS into everyday driving scenarios. Similarly, the Xing et al. [146] study used qualitative classification techniques such as K-means clustering, hierarchical clustering and PCA-based dimensionality reduction clustering to identify drivers' driving styles in order to improve driver intention recognition, decision models and overall driving safety. Using data from the Strategic Highway Research Programme database Chen and Chen [20], clustering and PCA were used to identify driving styles, revealing three distinct clusters: high speed with low variability, high speed with moderate variability, and low speed with high variability.

Several studies have also looked more closely at the characteristics of drivers with different driving styles. One of these studies is that of Several studies have looked at the characteristics of drivers with different driving styles. Eboli, Mazzulla, and Pungillo [33] used structural equation modelling (SEM) to explore how drivers' physical, behavioural and emotional conditions shape their driving style. They found that behavioural-emotional factors significantly influence driving style, with exhaustion, fatigue, worry, and anger leading to cautious driving, while depression, anxiety, and anger can lead to aggressive driving. This highlights the importance of considering both subjective and objective evaluations of driving style. Another study that looks at the relationship between driving styles and personality characteristics is the study by Taubman-Ben-Ari and Yehiel [129]. They explored the complex interplay between driving styles, personality characteristics and the As identified in the previous publication of Taubman-Ben-Ari and Yehiel [129], they used the same four driving style categories: reckless, anxious, angry, and careful. The findings identified that men and younger drivers tend to drive impulsively and aggressively. Women are more likely to drive anxiously, influenced by their educational background. Hierarchical regressions highlighted socio-demographic, personality and motivational factors as significant contributors to driving style variance. Furthermore, Herrero-Fernández [48] uses the MDSI Framework of Taubman-Ben-Ari, Mikulincer, and Gillath [130] for their research to find a relation between driving style and lifestyle. A questionnaire and Hierarchical linear regression models revealed both convergence and divergence in unsafe driving styles, while safe driving styles showed weaker associations with lifestyle behaviours.

3.7 Traffic hindrance

SWOV [126] have investigated traffic hindrances, including navigation systems' influence. The navigation systems offer drivers more control and less stress. However, navigation systems can distract the driver from the road and create safety risks. Other studies also examined the perception of hindrances that are experienced by drivers. Lieke Bos et al. [76] conducted a literature review of the user experience of road works in the Netherlands. The research highlights key factors that hinder perception, including unexpected delays that cause stress to road users. Through surveys of diverse user groups, the study primarily focused on the assessment of perceived hindrance, the evaluation of measures taken during road works (such as diversions, lane closures and speed reductions) and the resulting impact on the perception of hindrance. The findings revealed that unexpected delays caused the most inconvenience to road users, potentially leading to punctuality stress. The findings of the survey indicate that approximately 63% of respondents used the designated diversion route, while 25% used navigation systems and 10% opted for an alternative path. Within the sample that used the designated detour route, around 55% felt insecure during the detour about the route they took. The study demonstrates the effectiveness of timely information and effective measures in reducing inconvenience for drivers. Most drivers favour a combination of traditional signage and electronic text signs over digital traffic applications, which are ranked lower at 41%. This could be due to the fact that a significant proportion of drivers, approximately 30% of the respondents, choose not to use such applications. Roadside advertising signs can also cause traffic hindrances. Delving into the impact of roadside advertising on driver attention and safety, SWOV [125] presents an analysis of the impact of roadside advertising on driver attention and safety. The findings suggest that some types of roadside advertising, particularly those with moving components or emotional content, can distract drivers and potentially affect road safety. This suggestion is supported by Beijer, Smiley, and Eizenman [9] and Chattington et al. [18]. Oviedo-Trespalacios et al. [96] carried out a theory-based systematic literature review on the impact of roadside advertising signs, but no direct correlation between changes in driving behaviour as a result of roadside advertising and resulting road crashes was found.

3.8 Key findings from the literature review

The literature review highlights many variables important to traffic management, safety, and travel behaviour and goes further into the studies conducted on work zone safety, control measures, detours, and their impact on driving behaviour. Various studies with different methods and perspectives have contributed to a number of key findings, including:

The studies demonstrate the complex relation between TTC measures and their impact on safety and traffic flow in work zones. While various measures such as flaggers, traffic signs and digital displays have been used to reduce speeding and crashes, their effectiveness remains a challenge to quantify accurately. Digital countermeasures such as dynamic speed displays and variable message signs have shown limited impact on speeds, but can effectively divert traffic and reduce local congestion if relevant and up-to-date information is provided. Although there are concerns about potential driver distraction, integrated route guidance strategies using variable message signs offer promising ways to improve traffic management and overall road safety.

Research on drivers' responses to temporary traffic control measures highlights the importance of understanding how drivers respond to traffic information and how individual characteristics influence route choice. Socio-economic factors, familiarity with network conditions and expectations of travel time improvements play a key role in driver decision-making. Evaluations conducted in work zones show the variation in response to different measures, including the effectiveness of signage in reducing speeding and the impact of lane design on driving behaviour. In addition, research into driver response to navigation systems demonstrates the influence of in-vehicle technology on driving behaviour and route management. While navigation systems offer significant benefits in optimising route efficiency and improving driver experience, it is important to reduce potential safety risks and ensure the delivery of relevant, personalised information to the driver. In addition, the complex interaction of individual characteristics, psychological factors and environmental conditions is key to understanding driving behaviour. The research findings highlight the important influence of real-time information, prior experience, gender, age, experience and personality characteristics on drivers' responses to traffic information and their attitude to risk-taking. In addition, environmental factors, road conditions and vehicle characteristics have a significant impact on driving behaviour.

Driving behaviour includes driving skills and driving style, the second factor reflecting individual driving habits and choices. The study of Sagberg et al. [115] introduced a general definition for driving style: "a habitual way of driving that is characteristic of a driver or group of drivers". Driving styles are often clustered in three or four categories. The research of Taubman-Ben-Ari, Mikulincer, and Gillath [130] is often used for research in the field of personal characteristics and driving styles. They classified driving styles in the categories: of reckless and careless driving, anxious driving, angry and hostile driving and patient and careful driving. Other studies separated driving styles into three categories equal to aggressive, conservative and moderate driving. These three categories are related towards the three clusters defined by Chen and Chen [20] high speed with low variability, high speed with moderate variability, and low speed with high variability.

The literature review presents different methodologies used by researchers investigating different topics. Commonly, driving simulators, and data analysis techniques like logistic regression and linear mixed effects models are used to evaluate the effectiveness of different traffic control measures and to quantify the effects of the measures for specific case studies. Further, simulation studies are conducted to analyse changes in travel behaviour and traffic diversion. Other approaches in the field include the use of case studies and surveys, frequently in combination with simulation studies. For detour planning analysis, the methodologies implemented involve case studies, surveys, and traffic data analysis to optimise detour operations and design decision support systems.

However, despite the extensive research on potential detours, the impact of static traffic signs on traffic following a diversion remains relatively unexplored. Studies have explored the effects of digital traffic signs and GPS on perceived hindrances, safety around work zones and potential detours. However, there is a gap in research regarding the effects of static traffic signs, specifically on diverted traffic, the detours they take and the effects in such scenarios. Existing research relies primarily on simulation-based methods rather than observational approaches. This presents an opportunity for additional research to understand the effect of static traffic signs in directing diverted traffic around the work zone. Addressing this gap could provide valuable insights into the practical impact of traffic signage and traffic management during detours.

The literature review provides valuable insights into the driving behaviour of road users when faced with diversions and road closures. It identifies a number of factors, including emotional state, personal characteristics and navigation use, that influence driving behaviour. The findings from the literature on road user behaviour and decision-making are used in section 4 to formulate a comprehensive conceptual framework to describe detour behaviour.

4 Detour Behaviour Model

This chapter introduces a Detour Behaviour Model, which provides a structured conceptual framework for understanding driving behaviour and decision-making in response to road closures and associated detours. The purpose of creating this model is to address the research question of a suitable model to describe driving behaviour and route choices around detours. This model improves the understanding of detour behaviour by demonstrating the expected and observed driving patterns resulting from road closures and associated decision-making. It also explains driving behaviour and route choices in the context of temporary traffic measures implemented around road closures and detours.

The Detour Behaviour Model is constructed according to the methodology outlined in Figure 11. First (subsection 4.1, this chapter presents the guidelines for traffic management around road closures and detours in the Netherlands, following the CROW guidelines 96 [25]. These guidelines describe the placement of traffic signs and information dissemination protocols for road closures. When approaching a road closure and its associated detour, road users are faced with a series of decisions, which are explained in the following section (subsection 4.2). This route decision process is complex and influenced by several factors, discussed in subsection 4.3. Moreover, it is recognised that these factors not only influence the choice behaviour but also the driving style of road users (subsection 4.4). Based on the insights gained from the decision-making process and the driving styles modulated by these factors, four different driver profiles characterising road users navigating closures and detours are outlined in the following section (subsection 4.5). With the identification of different decisions and driving styles, the driving patterns that can occur around closures and detours are identified using the traffic measurements prescribed in the guidelines (subsection 4.6. Finally, these various analyses are combined to create a comprehensive Detour Behaviour Model (subsection 4.7).

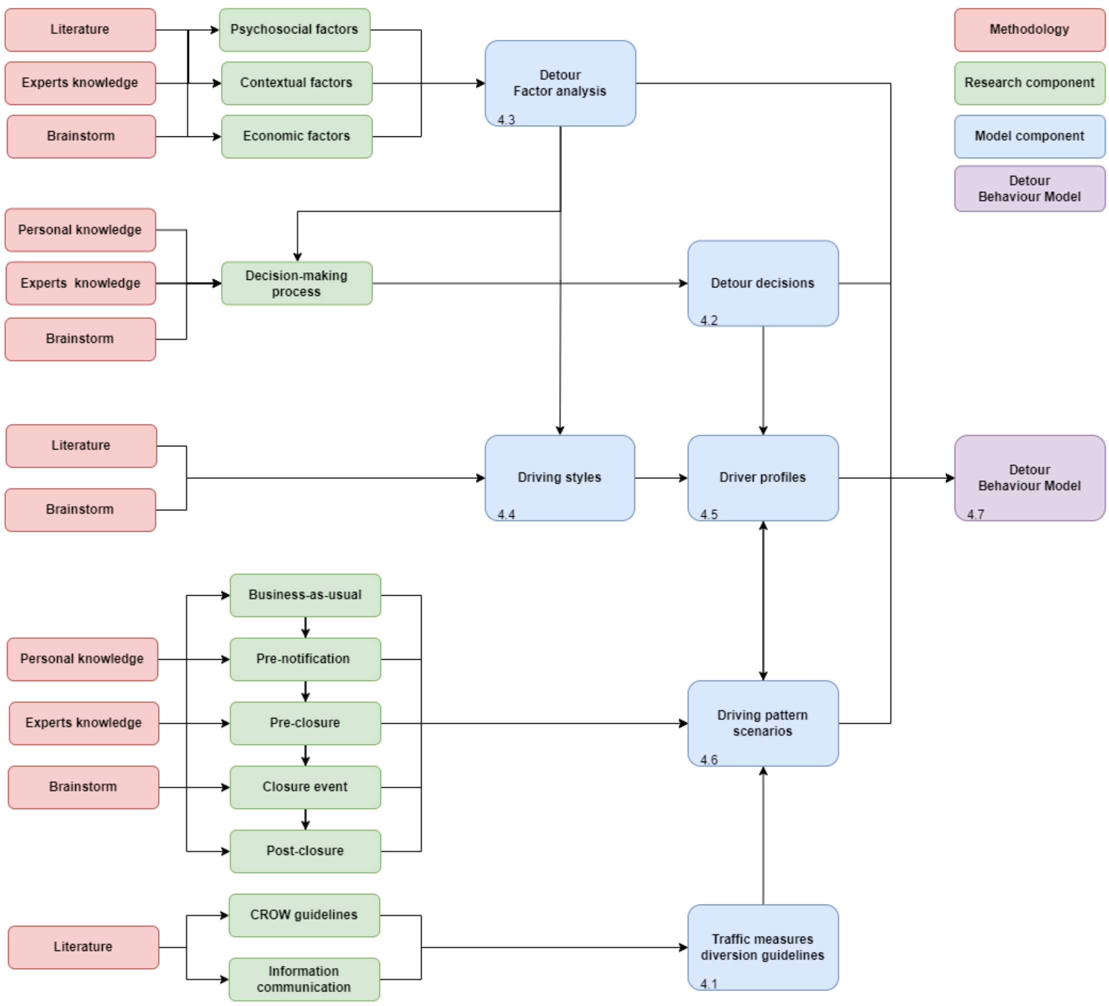

Figure 11: Detour behaviour model design approach

The information in this section is derived from four different sources, see Figure 11, but is mainly based on the insights provided by the experts who participated in the brainstorming session (Appendix C) and the literature review (section 3).

The experts participating in the brainstorming session cover roles within the temporary traffic management sector, including operations, work preparation, engineering and project management. Their collective expertise provides a comprehensive understanding of the complex dynamics involved in managing motorway traffic incidents. In addition, this chapter includes perspectives gained through personal knowledge and one-on-one conversations with work colleagues and regular road users. These informal discussions provide valuable first-hand experiences and perceptions of the challenges and impacts of road closures and detours. Finally, the conceptual framework developed was presented to the participants of the brainstorming session for evaluation. Including these information sources, this chapter aims to provide a comprehensive perspective on the behavioural dynamics of road users in response to detours.

4.1 Guidelines traffic measures motorway diversion

During road closures, traffic measures are fundamental to ensure safety and minimise disruption. CROW plays a key role in this by developing comprehensive guidelines and recommendations for road construction, traffic management and infrastructure development [139]. These guidelines provide a reference for professionals to ensure the safety, efficiency and sustainability of infrastructure projects. In order to effectively manage safety and traffic measures during road works, CROW has developed the 'Work in Progress' guidelines. These guidelines are essential for the smooth implementation of safety protocols and traffic management strategies. Specifically, Dutch motorways adhere to guideline 96a, CROW publication 'Werken op autosnelwegen' ('Work in Progress Measures on Motorways') [25]. Guideline 96a describes specific protocols and procedures aimed at minimising risks and maximising safety during motorway construction or maintenance activities [79]. This section discusses the guidelines outlined by CROW [25] concerning diversions caused by motorway roadworks.

4.1.1 Traffic measures during roadworks

The nature of the roadworks will determine whether they are carried out with or without traffic. When working with traffic, one or more lanes are usually closed and traffic is diverted to neighbouring or narrowed lanes around the roadworks. Conversely, if the work is carried out without traffic, the lanes are closed completely and traffic is diverted to alternative routes in the area to ensure that there is no traffic around the work zone [25].

Diversions are organised when a motorway lane, section or junction is closed. In the case of lane closures, the aim is to reduce the volume of traffic on a section of the motorway by diverting some traffic to an alternative route, thereby reducing delays on the original route. For complete road closures, all traffic should be diverted. A distinction is made between an advisory route and a detour [25]. An advisory route recommends a specific location or route to facilitate traffic flow by diverting some vehicles. A detour, on the other hand, indicates that the normal route is not available and that traffic must use an alternative route.

The design and procedure for such closures and associated diversions have been standardised. First of all, the area in which the roadworks and their surroundings are located has been divided into several zones: Approach Zone, Safety Zone, Work Zone and Traffic Zone [25]. In addition, the road users should be informed about the upcoming works and the associated traffic measures. The information is provided to the road users by using temporary static traffic signs. Traffic signs should indicate the location and nature of the works, the expected traffic impact, available diversion routes and details of the work zone.

The most effective safety measure in a roadworks zone is to divert all vehicles to alternative routes. However, this measure has a significant impact on the safety of road users on diverted routes, traffic flow and the quality of life of local residents. The following scenarios guide the design process of diversions:

- Road closure, diverting all traffic to alternative routes.
- Partial road closure, an advisory detour is in place to reduce traffic disruption by diverting part of the traffic.
- Road closure at a specific location affecting part of the traffic.
- Informing road users of an alternative route due to delays on the original route.

To facilitate traffic diversion, several management measures are essential [25]. Firstly, traffic should be diverted to roads of a similar or higher category to maintain efficiency and safety. It is also necessary to ensure that the additional travel time caused by the diversion is not significantly different from the original route in order to minimise inconvenience to road users. However, there are no specific guidelines on the maximum detour duration. Assessing the potential consequences, including the impact on road safety, traffic flow and noise pollution, is another important consideration. Coordination with emergency services is essential to ensure a rapid response in the event of incidents. Efforts should also be made to minimise public transport diversions to avoid disruption to the travelling public. Finally, the assessment of diversions for through traffic, local traffic and public transport should be prioritised to effectively manage traffic flow and minimise congestion.

Temporary static signs that supplement or replace permanent signs indicate accompanying measures. The decision to replace or supplement permanent signs depends on the impact of the situation and the changes involved [25]. Major traffic changes justify the temporary replacement of permanent signs with corresponding traffic signs of the same colour and composition. Minor traffic changes are communicated by yellow signs with black instructions. Detours due to roadworks typically fall into this category and are indicated by yellow signs, which are further explained in the next section.

4.1.2 Information communication diversions

The presentation of information about road closures and diversions is important for managing the response of road users. Static, dynamic and digital signs play a key role in informing drivers of planned road closures and diversions. In the Netherlands, the basis of providing information about the road closure and associated diversion is through static traffic signs. Clarity, visibility, consistency and correct placement of signs have a significant impact on diversion rates [84]. To raise awareness, various media campaigns, such as the 'Van A near Beter' campaign, target drivers using Dutch motorways and encourage them to plan their journeys in advance to avoid disruption [136][15][105]. These campaigns are effective in raising awareness of major road works and in supporting traffic management efforts [15].

Road users have limited information processing capacity. During vehicle operation, the driver performs a driving task, which reduces the extra information that can be recorded. Changes in traffic therefore put additional pressure on the driver's ability to perform the driving task and potentially reduce safety [25]. To minimize errors, guidelines focus on factors such as limiting the number of traffic signs and ensuring readability [24] [25]. Detour information is structured into levels based on the presentation of place names, numbers, or symbols, aiding road users in navigating through diversions [24]. The layout, design and placement of signs have a significant impact on road users' ability to understand information [81]. Consistent use of symbols, icons and messages across signs promotes clarity and reduces confusion. Early notification through strategic sign placement minimises congestion near detour points, improving safety [25]. Repetition of information across multiple signs increases awareness and helps drivers navigate effectively in unfamiliar areas.

Furthermore, the presentation of detour information is structured into three levels: detours with place names, detours with numbers or capital letters and detours with symbols [24]. The use of capital letters or numbers is preferred as a starting point, in a structured sequence of information that incorporates pre-announcements, detour announcements, and details on the planned route. For diversions outside urban areas, specific configurations are used based on this structured sequence of static traffic signage. These configurations will follow a basic plan similar to the one presented in Figure 12.

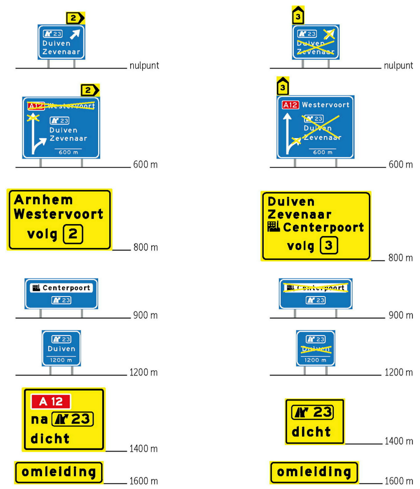

Figure 12: Basic plan configuration motorway diversions [25].
Nulpunt = start detour location.

The period including the road closure and the pre- and post-closure phases can be divided into five different phases: Business-as-usual, pre-announcement, pre-closure, closure and post-closure. During these phases, the information provided to road users follows the basic plan configuration.

Business-as-usual and pre-announcement: During these two phases, when there are no closures, road users will be informed of the traffic disruption caused by the works. The information to be provided during this period consists of the reason for the closure, the period and the times. An example of a pre-announcement sign is shown in Figure 13a.

Pre-closure, closure and post-closure phase: In the phases immediately before, during and after the closure, temporary information signs have been placed. These signs are located in the announcement area, where the road user is informed about the coming diversion. For this purpose, the various traffic signs shown in Figure 13b are applied. These traffic information signs can be divided into three areas: announcement area, (start)detour area and closure area. Depending on the type of closure, the closure area is entirely avoided when following the detour.

(a) Pre-announcement sign road closure.

(b) Announcement signs for road closure and detour.

Figure 13: Static traffic signage

While the focus of this research is on static signs, it is important to recognise that not only the number and placement of static signs influence the road user's information process and decision-making, but that other factors influence compliance with motorway diversions, including the presentation of information through electronic displays, digital platforms and navigation systems [64]. Furthermore, the real-time information that could be provided will have an impact on the road user's decision-making.

4.2 Detour decision-making process

As drivers navigate the roads, they are constantly faced with a range of decisions, from actions such as accelerating and braking, to more complex tasks such as manoeuvring through traffic or reacting to unexpected events. Each decision has an impact on safety, efficiency and the overall driving experience [98]. However, responses to these decisions vary depending on the situation and individual road user [145].

The complexity of the driving task has a significant impact on driving behaviour. The driving task involves a range of cognitive and perceptual processes including attention, memory, information processing and decision-making [40]. As drivers encounter changes in the road network, such as closures or detours, the cognitive demands of driving can be increased and require decision-making in a dynamic environment [123]. Tasks such as navigating detours or driving through congested roads can increase the driver's workload, potentially leading to errors, distraction or reduced situational awareness. Road users make different trade-offs while driving. For example, Aziz and Ukkusuri [6] explored the trade-off between emissions and travel time, showing that the fastest route doesn't always have the lowest emissions and that preferences vary between different demographic groups. Similarly, Tarko [128] explored drivers' preferred speeds, balancing safety against time savings, taking into account risks such as speeding tickets and collisions. These examples illustrate the different trade-offs drivers face, from environmental considerations to prioritising time over safety.

As a result of the brainstorming session Appendix C, trade-offs and different decisions made by road users related to diversion and road closures have been identified. Based on the findings, it can be concluded that the main decision to be taken is whether or not to follow the detour. Alternatives include: deviating from the recommended detour while following, or staying on the intended route despite potential obstacles. Other scenarios include the driver not being aware of a detour, choosing an alternative route or missing the start or route of the detour. This results in six possible main situations after the decision to follow the detour shown in Figure 14 has been made.

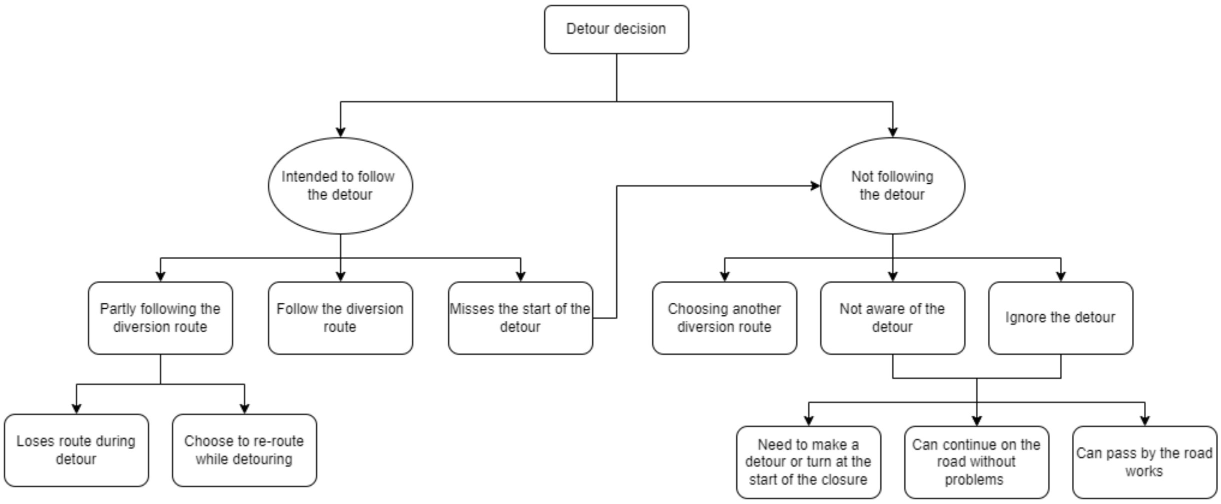

Figure 14: Detour decisions approaching road closure

4.3 Detour behaviour factors

Driving behaviour is influenced by a wide range of factors and the corresponding decision-making process involved in driving is complex [74]. Complexity occurs because driving performance and route choice are also influenced by the driver's age, emotional state, task complexity, stress and time pressure. As well as trip attributes such as travel time, distance and traffic conditions [14]. Based on the trade-offs, driving task complexity and decision-making processes and the different factors influencing these trade-offs, based on literature, expert information and own insights, three categories have been identified under which the different factors are grouped: psychosocial, contextual and economic. The different factors influencing road users' choices were also discussed in the brainstorming session. The results were elaborated in Appendix C and included in the factors. In Table 59 in Appendix D the different factors and categories are listed with the source of the information. The Figure 15 shows the diversion behaviour factors defined in the different categories. The units corresponding to the measurable contextual and economic factors are described in Table 5.

4.3.1 Psychosocial factors

Psychological factors play an important part in the decision-making process of road users as they navigate changes in the road network and adjust to new situations [77]. Possible decision-making processes are thereby following the current route or changing their route based on the provided information, because of for example road works. Various factors contribute to the decision-making process, including the decision to take a detour or for example to ignore the announcements. Another situation which could occur is failure to notice traffic changes. This could be a result of different factor combinations or a situation. These different factors involve a range of cognitive and emotional processes that influence how individuals assess risks, evaluate options and respond to information about new situations while driving [37] [33]. In addition, individual driver characteristics may affect driving behaviour in unknown situations [137] [142]. The following factors are some of the key psychological factors and driver characteristics that can influence detour rates:

Socio-demographic factors: Variables such as gender, age and driving experience can influence behaviour and responses to detours [142] [145].

Risk perception: Individuals have different perceptions of the risk associated with taking a detour. Some may feel the diversion is safer or less congested, while others may see it as unfamiliar and potentially risky. Perceptions of risk can influence whether drivers choose to use detours or stay on familiar routes despite potential delays [120] [45][134].

Time perception: Time perception plays a crucial role in the decision-making process for road closures and detours [82]. Drivers may have different perceptions of travel time along detour routes compared to their regular routes. Many drivers may judge the time based on their expectations and experience. For instance, some people may claim 'I don't have time to take a detour'. This statement might be based on previous experiences where detours appeared to take more time than anticipated, or on a feeling that the regular route is always the quickest or most efficient option. Additionally, the driver's perception of time may be influenced by the potential consequences of not adhering to the diversion. The driver may be unaware of the extent to which the risk of not following the diversion leads to additional time. Consequently, the perceptions of time may influence drivers' willingness to take detours.

Time pressure: Another comparable factor is time pressure. This is the time constraint resulting from the road user's schedule [104]. Road users who are not in a rush to get to their destination on time will be more likely to respond to a diversion than those who are in a more urgent need to get somewhere.

Familiarity area: Familiarity with the local road network and previous experience of using detours can influence detour rates. Drivers who are familiar with alternative routes or have successfully used detours in the past may be more likely to use detours [80] [131]. In addition, route familiarity has been shown to reduce drivers' cognitive demand and mental workload [16] [147]. However, increased route familiarity can lead to shorter glances at traffic signs, increased speed and inadequate responses to unexpected changes along the route [83].

Use of navigation systems: The availability and accuracy of navigation and GPS systems influence detour rates [85][73]. Drivers count on these systems to navigate detours efficiently and accurately, so they are more likely to choose detours that are well-supported and reported by navigation technology. However, due to distraction and lack of awareness of road conditions, in-car navigation could be a negative factor for road safety [55].

Situation awareness: The cognitive processes involved in driving, such as attention, memory and information processing, play a crucial role in how individuals navigate changes in the road network [45]. Drivers need to effectively process and prioritise incoming information, including road signs, signals and verbal instructions, in order to make informed decisions. Distraction or cognitive overload can lead to potentially dangerous situations on the road [11] [51]. Furthermore, the presence of advertising billboards along the roadside has been shown to result in a longer reaction time to traffic signs, increasing the potential for errors during performing the driving task [34].

Emotional state: Emotions also have a significant impact on driving behaviour. Drivers' emotional states, such as stress, frustration or excitement, can affect their ability to properly evaluate risks and make reasonable decisions while driving [113].

Vehicle characteristics: Vehicle characteristics such as model and age can influence driver behaviour. For example, an older vehicle may make people drive more carefully or the achievable speed may be lower.

Social distraction: The presence of passengers can affect the driver's attention. The same applies if the driver is talking on the phone. The driver's attention is not fully focused on the traffic environment.

4.3.2 Contextual factors

Contextual factors refer to aspects related to the environment, infrastructural and situational context in which road closures and detours occur. These factors include:

Road conditions: The condition of the roads along the detour route, including factors such as road surface quality, and the presence of construction or maintenance activities, can influence drivers' perceptions of the feasibility and safety of the detour [142].

Weather conditions: Weather conditions such as rain, snow, fog and ice affect road safety and driver visibility [142]. Additionally, the visibility of traffic measurements may be impacted by weather conditions. Low sun angles can reduce visibility, and dense fog can limit the distance from which signs are visible.

Light conditions: Lighting conditions play a crucial role in driver visibility, especially at night or in low-light situations [143]. Or the visibility during low sun or heavy rain [39]. Sufficient road lighting and visibility can increase the confidence of drivers to use detours, while poor lighting can create safety concerns and prevent drivers from taking new roads.

Speed limit: The speed limit along detours influences driver behaviour and perceptions of safety [36]. Drivers may be more willing to use detours with speed limits similar to those on their regular routes, while considerably lower speed limits may cause them to search for alternative routes or adjust their driving behaviour accordingly [64].

Construction activity status: Traffic flow is affected by the presence of active projects such as construction, maintenance or repairs along detour routes. Active work zones can cause traffic congestion, lane closures and reduced speed limits, all of which can influence a driver's decision to divert from or stay on their normal route. Road users are more likely to make changes when work is visible than when it is not, according to research by Steinbakk et al. [120].

Traffic congestion: Congestion levels on detour routes can impact travel times and driver comfort. High levels of congestion can cause drivers to look for alternative routes, while lower levels of congestion can make detours more attractive [133].

Traffic volumes: The number of vehicles on alternative routes can affect drivers' experience of safety and comfort. Heavy traffic can cause delays and frustration, discouraging drivers from using diversions during peak periods.

Time of the day: The time of day can have an effect on a driver's visibility, traffic patterns, and road conditions. During the day, visibility may be greater, making detours more attractive. However, the increased traffic volumes during the day make them less attractive [72].

Number of lanes: The number of lanes on detour routes can have an impact on both traffic flow and driver comfort. Wider roads with multiple lanes can accommodate higher traffic volumes and facilitate smoother detour experiences, while narrower roads with fewer lanes may lead to congestion and delays [142].

4.3.3 Economic factors

Economic factors refer to financial considerations that may influence decision-making in road closures and diversions. These factors include:

Time differences: Variations in travel times between detour routes and regular routes can influence driver decisions [111]. Longer travel times on detour routes may discourage drivers from choosing the detour.

Extra costs: An additional reason for not wanting to take the detour may be higher expenses. The detour may result in additional time and distance, which could lead to that the vehicle needs more fuel, increasing the cost.

Distance differences: A detour often results in an additional distance to be travelled to reach the destination. The length of the detour may influence drivers' decisions to follow it or not. In addition, a long detour can create uncertainty among drivers that they cannot find or follow the road correctly and therefore choose to follow another known route.

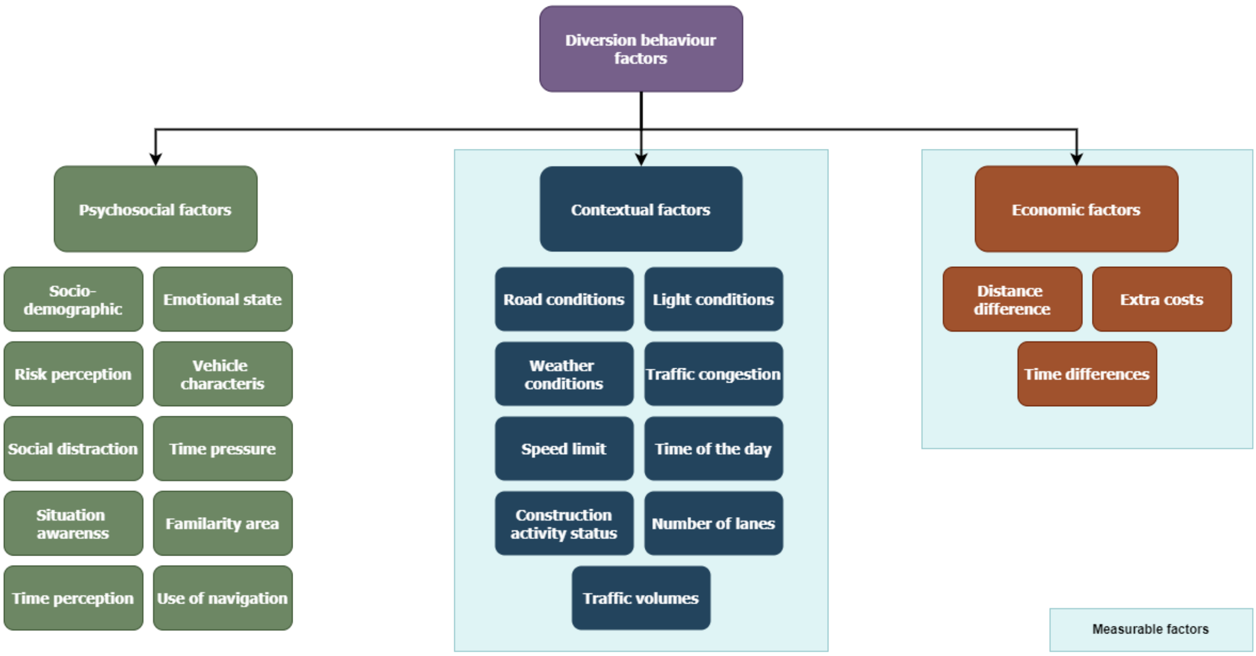

Figure 15: Factors influencing Compliance with Road Closures and Detours
Measurable factors units are shown in Table 5

Table 5: Measurable factors model

Units measurable factors						
Contextual factors						
Road conditions		Good	Poor			
Light conditions		Daylight	Night	Dusk		
Weather conditions		Freezing	Sunny	Rainy	Storm	Fog
Speed limit		Speed limit road				
Construction activity status		Visible	Not visible			
Traffic congestion		Lower speed	Delay	Congestion	No delay	
Time of the day	Pre-closure	Time period				
	Closure					
	Post-closure					
Number of lanes		#				
Traffic volumes	**Motorway**	High	Mean	Low		
	Ratio	Volume motorway / number vehicles closure road				
Economic factors						
Time differences		Extra time following diversion in minutes				
Extra costs		Vehicle loss hours in €[138]				
Distance difference		Extra distance following diversion in km				

4.4 Driving styles around detours

As a result of the previous section, it is identified that many factors can influence a driver's behaviour and that each road user is different. The literature review (section 3) showed that different factors can lead to distinct driving styles among road users [32]. These driving styles, which Sagberg et al. [115] defined as habitual patterns of driving characteristic of individual drivers or groups. In this section, different driving styles are determined as a result of the literature review section 3 and brainstorm session Appendix C.

Existing research, discussed in section 3, emphasises personal characteristics such as gender, age and emotional states as significant contributors to driving style. Attempts have been made to categorise driving behaviour. Some studies classify driving styles into three broad categories: average, aggressive and conservative [78, 114]. These categories, derived through cluster analysis and using measurements such as flow rates, vehicle speed and acceleration, provide a simplified representation of driver behaviour. More nuanced classifications have been proposed by Taubman-Ben-Ari, Mikulincer, and Gillath [130] and further refined by Huysduynen et al. [54], introducing four distinct categories: Reckless and Careless Driving, Anxious Driving, Angry and Hostile Driving, and Patient and Cautious Driving. In particular, the aggressive category is split into two separate categories, compared to the three simplified classifications. Later validation studies by Huysduynen et al. [54] identified six driving styles, each characterised by unique attributes shown in Figure 76 in Appendix B. While the detailed driving style framework provides a detailed level of understanding, its attributes are difficult to measure experimentally compared to quantifiable measurements such as traffic flow and vehicle speed. Furthermore, given the focus of this study on motorway detour traffic conditions, existing driving style categories may not be contextually relevant. In addition, there is a distinction found within the literature in more detailed and general driving styles categories. To address this, driving styles specific to detour scenarios are constructed based on available information, insights from brainstorming sessions, personal interviews, and author expertise.

The brainstorming session resulted in different driving style profiles, as shown in Figure 77 in Appendix C, regarding detour behaviour in particular. These classifications are based on the driver's level of experience and familiarity with the area. The resulting driving style categories include the alert (experienced) driver (characterised by higher average speed), the distracted or reckless driver, the uncertain (less experienced) driver and the average driver. These four categories, identified in the brainstorming session, provide a detailed description of driving styles. In addition, participants in the brainstorming session were requested to identify more general driving styles to enable comparison with those described in the literature. As a result, three additional driving styles emerged: Average Driver (frequent and confident driver), Conservative Driver and Habitual Driver (driver familiar with the surroundings).

The driving style categories derived from the brainstorming session are compared with those in the literature, Table 6. The brainstorming session identified four distinct driving style categories, which matched three categories in the literature. The

’distracted or reckless driver’ identified in the brainstorming session corresponds to similar classifications in the literature, but includes more nuanced subtypes within the category: ’reckless and careless driver’ and ’angry and hostile driving’. However, specific categories such as ’alert experienced driver’ or ’the speeder’ are absent in the literature. In addition, comparisons are made between the more simplified categories found in the literature and the more general categories that emerged from the brainstorming session. In both cases, the ’average driver’ and the ’conservative driver’ are identified. However, while the brainstorming session identifies the ’habitual driver’, the literature identifies the ’aggressive driver’.

Driving styles					
Brainstorm		**Literature**		**Combined**	
Detailed	**General**	**Detailed**	**General**	**Detailed**	**General***
Alert experienced driver The speeder	Average driver	Reckless and Careless Driver	Conservative driver	Incautious Driver	**Aggresive driver** (higher avg speed)
Distracted or Reckless driver	Conservative driver	Anxious driving	Average driver	Anxious Driver	**Conservative driver** (lower avg speed)
Insecure driver (Less experienced)	Habitual driver	Angry and Hostile Driving	Agressive driver	Skilled Driver	**Habitual driver** (slightly higher avg speed)
Average driver		Patient and Careful Driving		Patient Driver	**Average driver** (avg speed)

Table 6: Driving styles
* Selected driving style category distinction in this research

The different driving style categories identified are combined to create categories that cover the driving styles that occur around detours. These combinations are shown in Table 6. For a more detailed description of the driving styles, the following four categories are identified Incautious Driver, Anxious Driver, Skilled Driver and Patient Driver. This research is not able to identify the psychological factors involved in driving behaviour. For this reason, the more general driving styles identified were also taken into account. Therefore, the four different styles are considered as possible driving styles by adding the habitual driver. In addition, these styles are further categorised by a corresponding average speed in order to introduce the possibility of identifying them around road closures. This resulted in the following combinations: Aggressive driver (higher average speed), Conservative driver (lower average speed), Habitual driver (slightly higher average speed) and Average driver (average speed).

4.5 Detour driver profiles

This research focuses on analysing driver behaviour in response to motorway traffic measures and detours caused by road closures. By considering detour decisions and driving styles in these scenarios, detour driver profiles can be developed. This section therefore uses detour decisions as the basis for defining four different driver profiles, each associated with corresponding driving styles likely to be encountered around road closures.

In subsection 4.2, the decision-making process and the choices involved in road closures and the associated detours are investigated. This research leads to six main situations around a detour, as shown in Figure 14, which result from the decision to either follow the detour or not. However, observation measures cannot distinguish whether a driver is unaware of the detour, intentionally disregards the detour, or misses the start of the detour when they are not following the signage. In addition, the feasibility of determining whether traffic partially adheres to the detour depends on the measurement locations. Furthermore, the underlying reasons for the decision made remain unmeasurable. Consequently, observations typically identify three main choices:

1. Following the diversion
2. Ignoring the diversion
3. Choosing another diversion route

In addition to the temporary signs placed at the time of the closure, a pre-notification sign will be placed at the closure location two weeks in advance. Drivers using the road during this two-week period will be informed of the time and duration of the road closure. These drivers may choose to adjust their plans accordingly, such as leaving at a different time, staying at home or taking a different route to their destination. However, these alternative actions are not captured in the observation studies conducted around the closure locations during the closure period. Consequently, this scenario introduces additional situations that may arise around a detour, as shown in Figure 16. As a result of the identified main scenarios around the detour, four driver profiles can be developed:

- **Driver profile 1:** Following the detour
- **Driver profile 2:** Not following the detour
- **Driver profile 3:** Choosing an alternative route
- **Driver profile 4:** Decision to avoid closure location

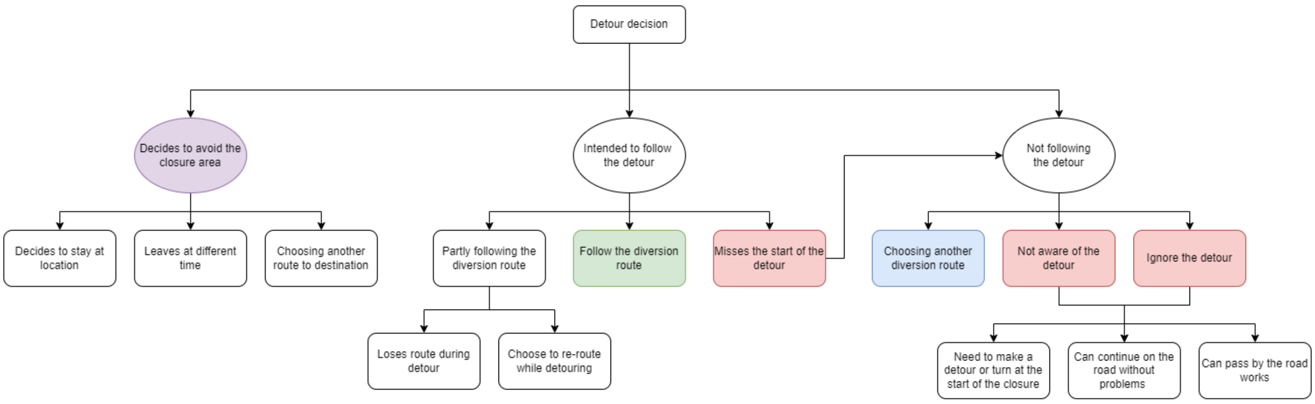

Figure 16: Detour decisions

Driver profile 1 consists of the decision of following the detour (green) in Figure 16. By conducting an observation study there is no identification of the reason for not following the detour and therefore Driver Profile 2 covers three different scenarios (red). Driver profile 3 includes the road users taking another route (blue). Driver profile 4 is the road user who decided to avoid the road closure area (purple).

In addition, the driver profiles are linked to potential corresponding driving styles based on the results of the brainstorming session. The expected driving styles corresponding to the four driver profiles are listed in Table 7. The expected driving styles suggest that the habitual driver may appear in any of the choice scenarios. However, the aggressive driver is expected mainly when the detour is not followed, while the conservative driver is expected mainly when the detour is followed. The average driver, on the other hand, is expected to both follow the detour and choose another route.

Table 7: Expected driving styles of detour decisions

Detour decisions	**Driving styles**			
	Aggresive driver	**Conservative driver**	**Habitual driver**	**Average driver**
Driver profile 1: Following the detour		x	x	x
Driver profile 2: Not following the detour	x		x	
Driver profile 3: Choosing an alternative route			x	x
Driver profile 4: Decision to avoid closure location			x	

4.6 Driving patterns

The previous sections have highlighted the different choices that can be made by road users as a result of closure and associated diversion. In addition, multiple factors that can influence a road user's choices and driving style are determined. As a result, four different driver profiles around a diversion have been identified. In this section, the different scenarios of driving behaviour that can occur during a diversion are examined. This involves looking at the possible movements around the road signs and the possible routes. The possible changes in speed are not taken into account. This is due to the fact that it is not possible in this study to analyse the speed per driver. However, for each scenario, three main situations are possible in terms of speed: speed decreases, speed remains the same and speed increases.

The closure process consists of five successive phases: the business-as-usual phase, the pre-notification phase, the pre-closure phase, the closure phase and the post-closure phase. As different patterns of driving can occur in each phase, the different phases are examined separately. The scenarios have been developed on the basis of personal insights as well as insights from one-to-one conversations with experts and the results of the brainstorming session in Appendix C.2.1.

4.6.1 Business-as-usual phase

The business-as-usual phase is the baseline situation. In this situation, there are no traffic restrictions. Traffic can follow the normal routes and there are no changes to the traffic situation.

4.6.2 Pre-notification phase

There will be no major traffic changes during the pre-notification phase. However, prior to the closure, notification signs will be installed at the location of the upcoming closure to inform road users of the upcoming work and the associated closure of a specific section of road. Although there will be no closures and therefore no traffic disruption, there may still be some traffic changes. In the case of placing the pre-announcement sign on the road to be closed on the secondary road network of the motorway, no patterns can be analysed from the data available in this study and therefore no possible scenarios are identified. The changes in traffic behaviour when the pre-announcement sign is placed on the motorway may be visible around the sign. However, there are no visible changes in driving behaviour that can be identified in terms of possible movements and therefore no specific driving patterns are developed for the pre-announcement phase.

4.6.3 Pre-closure and Post-closure phase

The phases before and after the road closure are used to place or make visible, remove or make invisible, the signs. During both phases, two different stages can occur. Firstly, not all traffic signs relating to the closure may have been installed yet. For logistical reasons, the signs are not all be installed at the same time, resulting in some signs being visible before others. Similarly, the same delayed invisibility may occur when signs are removed after the closure. Secondly, depending on the circumstances, the closure may begin immediately after the signs are installed, or the signs may remain visible for a period of time without the road actually being closed (or removed). Alternatively, there may be cases where traffic signs have been previously installed but are not visible to traffic because they have been obscured or reversed. In such cases, the signs are phased in (made visible) during the pre-closure phase, after which the closure will start. In addition, there's often a gap between when all the signs are visible and when the closure comes into effect. This is used to proactively divert traffic to ensure that the work can be carried out safely. During the pre-closure and post-closure phases, similar driving patterns can occur during both stages. In Table 8 the different driving patterns scenarios are introduced. Driving scenarios 1 to 6 occur in the pre-closure phase and scenarios 19 to 24 in the post-closure phase.

Table 8: Pre-closure and post-closure phase driving patterns

Scenario	Changes Driving Behaviour	Explanation
Traffic signs partly visible		
1 & 19	No changes in driving behaviour	The road user does not yet follow the temporary signs and continues on the road. This does not affect the route the road user is currently following.
2 & 20	Road users follow the temporary traffic signs.	After passing the last visible sign, the driver decides to continue on the normal route. The road user does not encounter any hindrance.
3 & 21	Road users follow the temporary traffic signs. However, after passing the last visible sign, the driver does not know where to go and have to find another route.	After passing the last visible sign, the driver does not know where to go and have to find another route.
All traffic signs visible		
4 & 22	Road users will follow the temporary signs in accordance with the new measures.	Following the detour indicates that the road user has seen the announcement and is following it. As a result, the road user will deviate from their original plan and follow an alternative route.
5 & 23	The road user does not yet follow the temporary signs and continues on the road. This does not affect the route the road user is currently following.	Driving through when the closure is announced can represent a variety of driving behaviours. The road user has not seen the announcement. The road user did read or understand the announcement and knows that the road is open. Another possibility is that the road user ignores the announcement.
6 & 24	The road user does not yet follow the temporary signs but changes to another route.	A possible reason for the use of an alternative route is that this route is quicker to the destination than the detour route.

4.6.4 Closure phase

A closure announcement on the motorway is used to inform drivers of either a section of the motorway being closed or a closure affecting the surrounding secondary road network. The availability of the detour may vary depending on the nature of the roadworks. Typically, closures involve either the complete closure of a section of road or the closure of an exit or access ramp. Alternatively, there may be partial closures, where one or more lanes are closed, resulting in reduced road capacity. In addition, exit or access ramp closures may restrict access to certain destinations. This study specifically examines a closure on the secondary road network of the motorway, with the closure and diversion route indicated on the motorway.

When driving from the motorway to the closed road, the driver will encounter various traffic control measures, which are organised into different areas: the announcement area, the detour initiation area and the road closure area. In the announcement area, traffic signs indicate that a particular section is closed or unavailable, together with additional information about the designated detour (see Figure 13b). The start of the detour marks the point at which drivers must deviate from their current route. In contrast, the road closure indicates the point at which the road becomes inaccessible and further travel is disrupted. The alternatives available depend on the type of closure. This research focuses on a full road closure within the motorway secondary road network, which is discussed in this section. Other closure scenarios are detailed in Appendix E. Road users following the detour route will avoid the closure area and are therefore excluded from the analysis of potential scenarios within this zone. Table 9 outlines the expected traffic flow patterns around the detour and road closure across the three traffic control zones during the closure phase.

Table 9: Closure phase driving patterns

Scenario	Changes Driving Behaviour	Explanation
Announcement Area		
7	The road user follow the detour	The road user has seen the information on the first or second traffic sign and has the intention to follow the diversion
8	The road user follow an alternative route	The driver decides to take a different route than the suggested detour. The driver may have the possibility to take an alternative route that may be even more convenient to the destination than the recommended route.
9	The road user does not follow the detour	Drivers do not respect or are unaware of road closure announcements. Another reason for passing through is that it is not clear to the road user that there is a hindrance on their intended route.
Start Detour		
10	The road user follows the detour	The road user deviates from the original plan and continues the route indicated by the detour signage.
11	The road user fails to notice the start of the detour.	
12	The road user proceed past the start of the detour.	The driver did not intend to follow the detour, or the road user does not notice any of the traffic signs indicating the detour.
Road Closure Area - Road closure on secondary road netwerk		
15	The road user takes the available shortcut	Drivers choose an alternative route available at the location of the closure.
16	The road user turns back to the motoray	The road users will have to turn around at the location of the closure in order to return to the motorway or to an alternative route. Because there is no shortcut available.

4.6.5 Driving patterns around road closure secondary road network

The scenarios identified during the different phases of the road closure may follow each other at different times, as it is not known what decisions a driver will make in the vehicle. Therefore, Figure 17 shows the corresponding scenarios and interactions for the different phases of the closure around the road closure. In addition, around each scenario, it is possible to identify speed changes by the road user. The following speed adjustments may occur:

1. No changes in overall average speed of the traffic
2. Decrease in average speed
3. Increase in average speed

There may be several reasons for the change in speed that cannot be measured in this study. However, a number of possible reasons were identified during the brainstorming session. A decrease in speed could indicate that drivers are influenced by seeing temporary traffic signs and do not want to make wrong decisions due to the changed situation, or that they reduce speed because they doubt that the information applies to them. An increase in speed may indicate that drivers are trying to make up for time lost due to the diversion by driving faster.

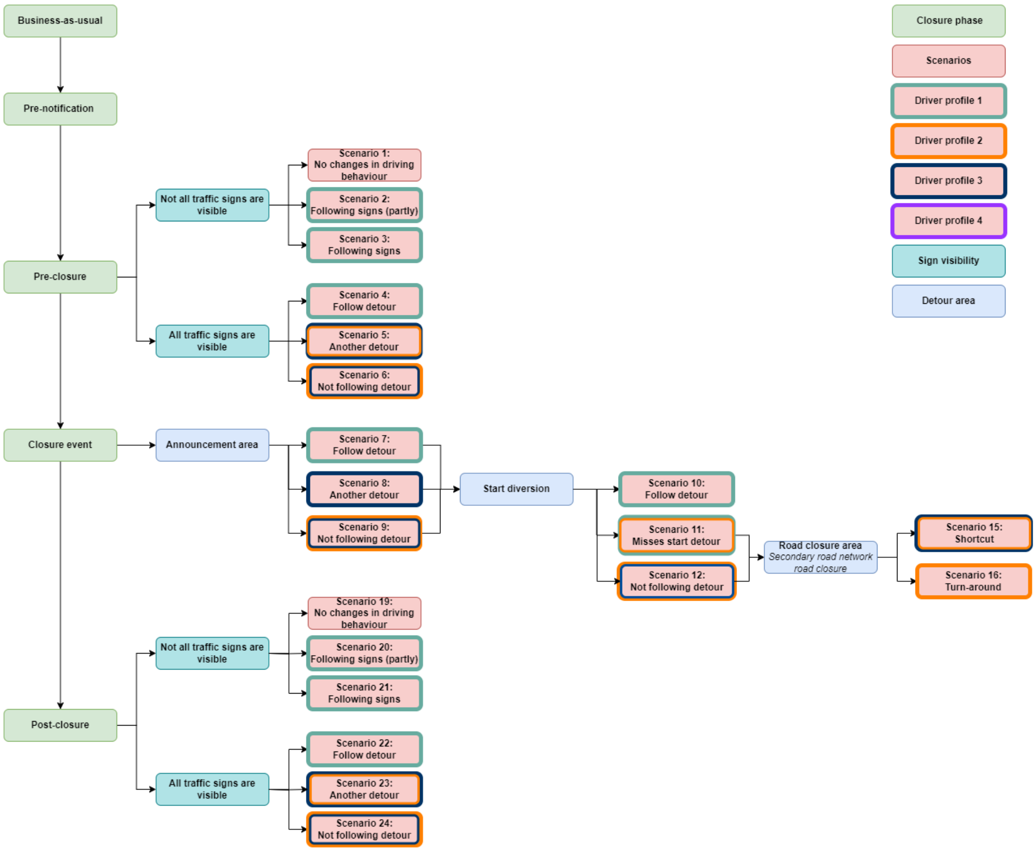

Figure 17: Driving patterns around road closure

4.7 Design of detour behaviour model

In the previous sections, different aspects of detour behaviour have been identified, from which four driver profiles and different driving patterns have emerged. In this section, the different aspects are discussed and combined into a model of detour behaviour. Around a road closure, there are five different time phases during which drivers can make various decisions and adopt different behaviours. These decisions are influenced by a variety of factors, including psychosocial factors, contextual and economic factors. The main decision drivers are confronted with is whether or not to follow the detour. Depending on this decision, different driving patterns develop around a closure and its associated detour. These patterns can be associated with established driver profiles. Based on these different aspects, the detour behaviour model shown in Figure 18 is developed.

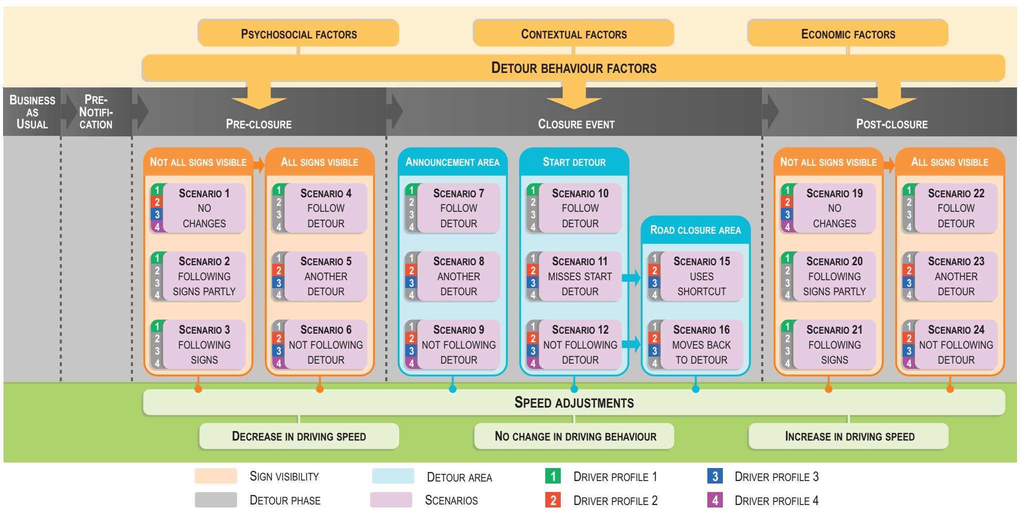

Figure 18: Detour Behaviour Model

5 Case Study A9 exit 6 Aalsmeer

The first case study focuses on the A9 towards Badhoevedorp at the Aalsmeer exit. Here, measurements were carried out by closing the road towards Schiphol Airport on the secondary road network of the A9 motorway. The aim was to investigate how traffic reacts to static temporary traffic signs. Measurements were taken on the motorway in the area surrounding the traffic signs and on the exit ramp beside the closed road, and ANPR cameras were positioned at the exit and entrance ramps to identify non-compliant vehicles, in order to gain insight into the impact of traffic management measures for road closures on the secondary road network.

This chapter starts with an overview of the scope of the case study, focusing on two main categories: motorway observations and route choice observations. The approach of this chapter is shown in Figure 19. Firstly, the analysis carried out and the results relating to motorway observations are presented. Using data from the NDW, the analysis examines the overall average speed of traffic and the volume of traffic per hour on the motorway. This involves establishing a baseline by analysing the average volume and speed of traffic on the motorway, against which the results of days with traffic management measures due to road closures are compared. The closure days are then compared to the baseline, followed by statistical analysis to identify any significant differences.

In addition, the chapter examines route choices around road closure using data from the ANPR cameras. This analysis begins with a discussion of the changes in traffic volumes observed on days with and without road closures. Next, a linear regression analysis is used to derive an estimate of expected traffic flows, which are compared with the observed traffic flows during road closures. This information allows the determination of compliance rates, which differentiate between vehicles that comply with traffic measures and those that do not. Statistical analysis is then used to test the significance of these results.

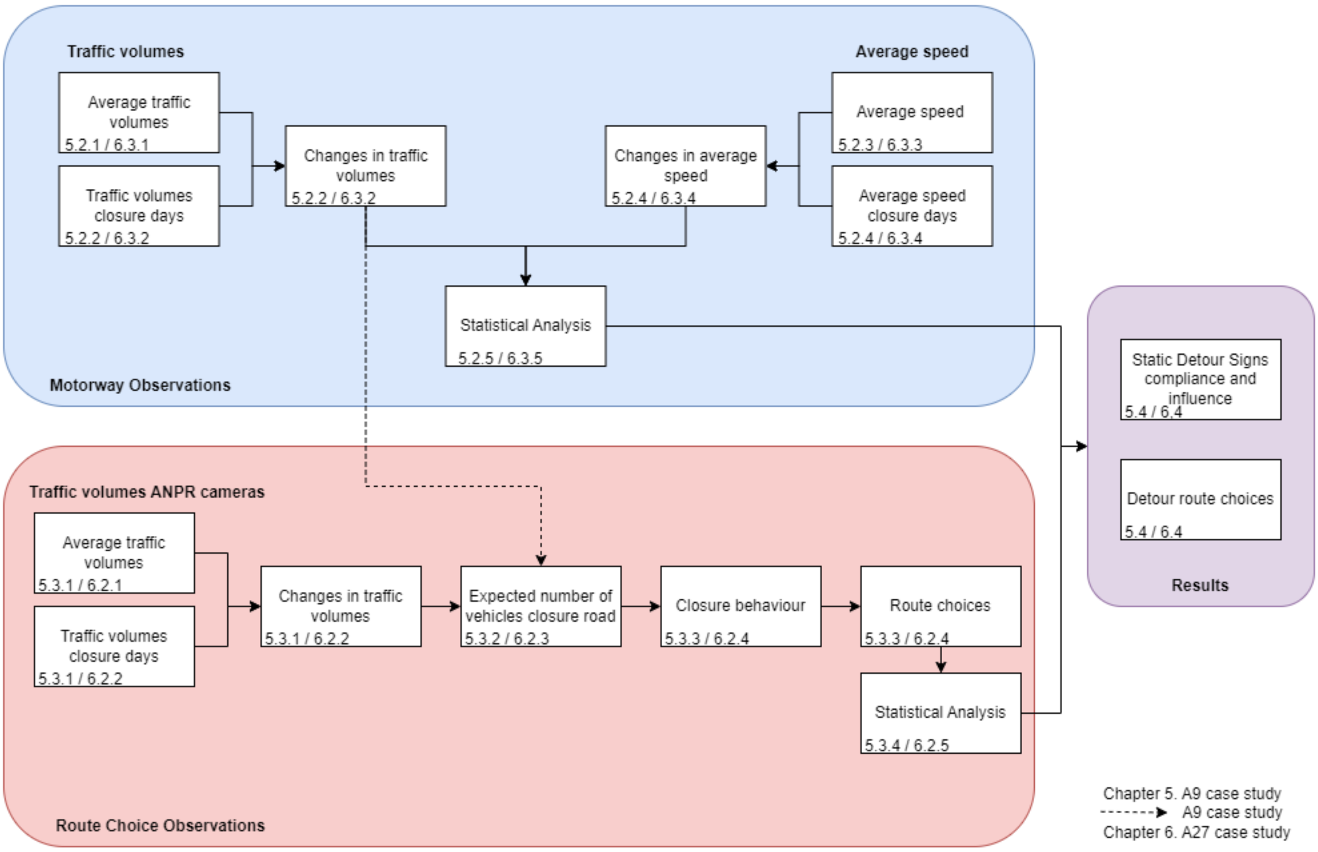

Figure 19: Observation study approach

5.1 Scope A9 exit Aalsmeer

The A9 motorway is being widened to provide an additional lane. As a result of this work, a number of viaducts will also have to be widened. This includes the Schiphol Bridge. Due to this work, the access road to Schiphol at exit 6 Aalsmeer will be closed in both directions for several days between 05-02-2024 and 14-02-2024 from 20:00 to 04:00. During the construction work, the exit will remain open for traffic to and from Nieuwemeerdijk. In order to analyse the behaviour around the closure of the road to Schiphol immediately after the Aalsmeer exit, ANPR cameras were installed on the relevant exit and access ramp and the motorway around the exit was analysed, as shown in Figure 5.

The measurements in the case of closing of the access road towards Schiphol Airport are conducted on Tuesday 06-02-2024 between 20:02 and 04:18, and on Thursday 08-02-2024 between 20:28 and 03:05. Both days are analysed separately and then compared to assess the behaviour of road users around the closure. The different corresponding time periods of the closure phases for this case study are shown in Table 10. The ANPR cameras are installed on 01-02-2024 (between 20:00 and 21:00) until 14-02-2024. For this purpose, the measurements from Thursday 01-02-2024 to 02-02-2024 were used as a baseline for the situation without closure. On Tuesday 13-02-2024 the ANPR cameras were also in operation. However, the data cannot be used as a baseline as there was a complete closure of the exit ramp on that day.

Table 10: Time periods, closure phases

	Tuesday 2024-02-06	**Thursday 2024-02-08**
Pre-closure	19-20	19-20
Closure	20-04	21-03
Post-closure	04-05	03-04

This case study focuses on vehicle behaviour when approaching a closure on the secondary road network. The impact of temporary signs on the A9 motorway is assessed using traffic volumes and average speeds on the motorway. In addition, the use of ANPR cameras is used to analyse road users who do not follow the signs.

5.2 Motorway observations

Detection loops are used to conduct observations on the motorway around the slip road and temporary traffic signs. Figure 5 shows which loop locations are used for this analysis. The data from the loops include the volume of traffic per hour and the average speed of the traffic per hour. The two loops for exits HMP 30.8 and 31.2 are analysed to determine the change in traffic behaviour at the announcement and detour signs. The difference between the detection loops HMP 31.2 and HMP 31.6 reflects the number of vehicles that have taken the exit Aalsmeer; equivalently, the difference between the detection loops HMP 31.6 and HMP 32.0 represents the number of vehicles that have taken the access ramp to the motorway. The change in road user behaviour around the exit where a closure occurs on the underlying road network is analysed using loops HMP 31.2, HMP 31.6 and HMP 32.0.

Data derived from the loops, NDW data, have been retrieved for Tuesdays and Thursdays in the months of January to March for the years 2022 and 2023. For the year 2024, this was done for the month of January and the month of February until 14 February.

Road behaviour is analysed for different phases around a closure. Business as usual, pre-closure, closure and post-closure are considered. The pre-announcement phase is when there are no measures in place and only a temporary traffic sign has been installed to announce when the road will be closed. This announcement sign is placed on the road to be closed, in this case the Schipholweg. For this reason, it is not covered in the motorway observations, as it is not visible to traffic on the motorway.

5.2.1 Business-as-usual phase: Motorway traffic volumes over the years

The business-as-usual phase is the period when there are no closures and traffic is not affected by the works. By averaging the different detection loops and comparing them with other years, a frame of reference can be established. The frame of reference can be used to compare differences in the situation with traffic measures.

The reference frame is determined based on the average traffic volumes found by the detection loops for the different years. The minimum and maximum values found in 2024 are also determined. A different reference frame will be determined for the pre-closure phase, closure phase and post-closure phase. This is due to the fact that the phases do not occur in the same time periods.

Pre-closure phase: The pre-closure phase will take place on Tuesday 06-02-2024 between 19:00 and 20:00. On Thursday 08-02-2024 it will take place between 19:00 and 21:00. The results are presented in Figure 20. The results show that, on average, there is more traffic on the motorway on a Thursday than on a Tuesday.

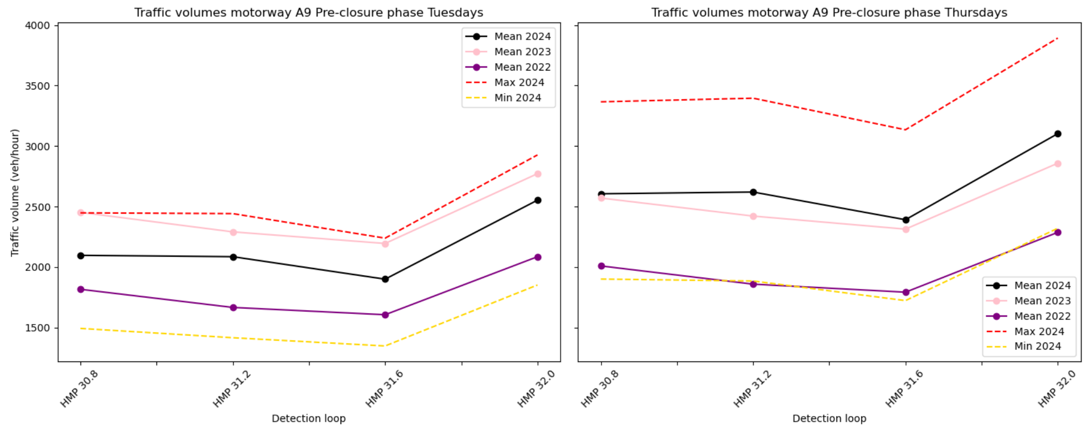

Figure 20: Mean traffic volumes A9 Pre-closure phase over the years 2022, 2023 and 2024

The results show that the volume of traffic crossing the A9 motorway increases every year. The difference between 2022 and 2023 is larger than the difference between 2023 and 2024. This is in line with the trend forecast of Knoope, Faber, and Francke [67], which states that traffic on Dutch roads increases after the removal of corona protection measures. This increase in traffic is also one of the main reasons for the widening of the A9 motorway, because without the widening and the current capacity, there is already a lot of congestion on the Badhoevedorp section [107]. The NOS article written by Roeland Müller [112] discusses that the prediction is that the problem of congestion will increase in the coming years. There are only measurements available until the closure days. For these reasons, the mean of the months January until March of 2024 is chosen as the frame of reference for changes during closure.

Closure phase: The closure phase will take place on Tuesday 06-02-2024 between 20:00 and 04:00 and on Thursday 08-02-2024 between 21:00 and 03:00. Average values were determined for each hour of the closure period. The results for the period 21:00 - 22:00 are shown in Figure 21. The other time periods are shown in Table 60 in Appendix H.

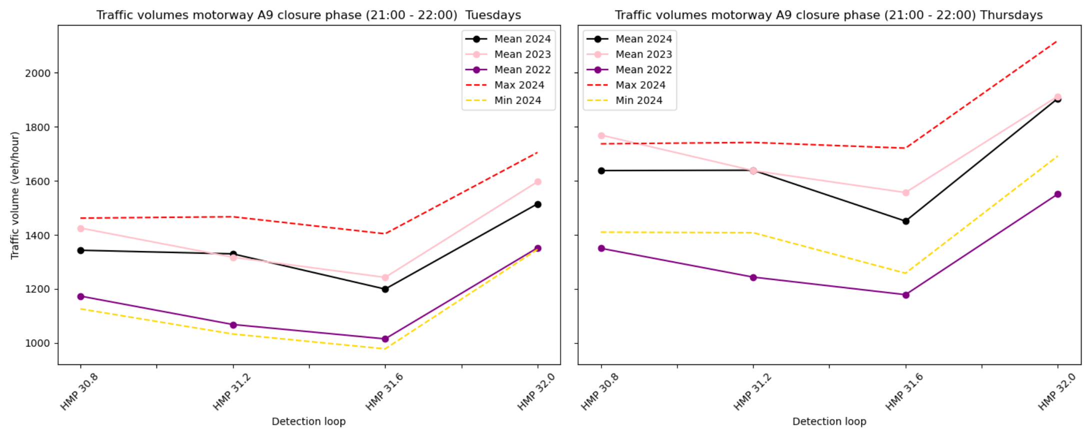

Figure 21: Mean traffic volumes A9 closure phase (21:00 - 22:00) over the years 2022, 2023 and 2024

The results for the 21:00 - 22:00 period give different results to the pre-closure period. The average value found in 2023 is higher for detection loops HMP 30.8 and HMP 31.6 than the values found in 2024. The same results can be found for the other periods of the closure phase in the Appendix. The numbers in 2023 for detection loops HMP 30.8 and HMP 31.2 are less constant than for 2024, but no traffic can leave or join the motorway around these loops. For this reason, it was decided to use 2024 as the reference year for the closure phase.

Post-closure phase: The post-closure phase for the work started on Tuesday 06/02/2024 ended on 07/02/2024 at 04:18. Therefore, the post-closure phase took place between 04:00 and 05:00. The work started on Thursday 08-02-2024 ended on Friday 09-02-2024 at 03:05 and therefore the post-closure phase took place between 03:00 and 04:00. The results of the post-closure phase are shown in Figure 22. The results show that 2024 has the highest traffic volumes for most detection loops. In addition, the values for 2022 and 2023 were not found above the minimum value in 2024. It was therefore decided to use 2024 as a reference for changes.

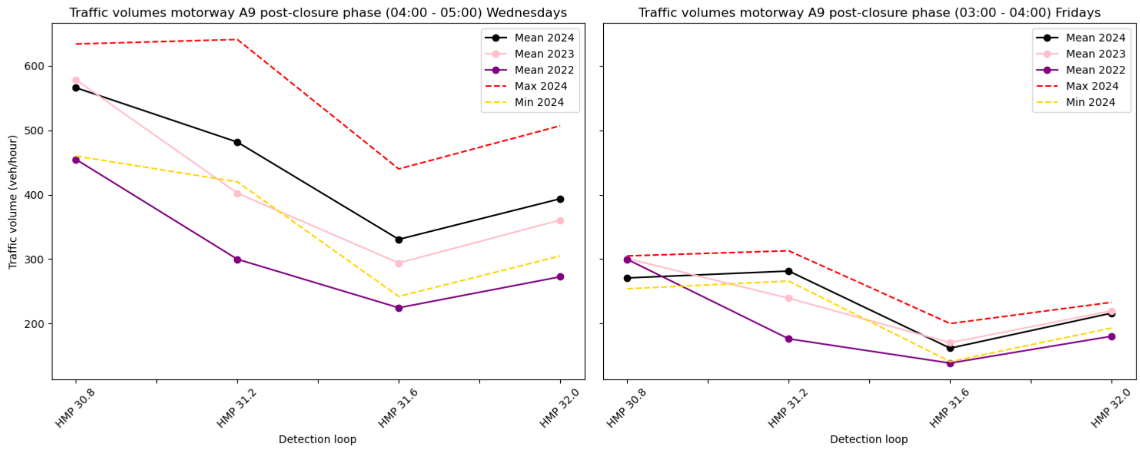

Figure 22: Mean traffic volumes A9 post-closure phase over the years 2022, 2023 and 2024

5.2.2 Motorway observations traffic volumes

In order to analyse the change in behaviour on the motorway, it is important to know whether there is a change in the volume of traffic on the motorway around the Aalsmeer exit, where the Schipholweg is closed on the underlying road network. In addition, the traffic volume for Thursday 1 February is also included, as it is used as a reference measurement for the ANPR cameras.

Pre-closure phase: During the pre-closure period, the Schipholweg is not yet closed and takes place between 19:00 and 20:00. The results of the traffic volumes compared to the minimum, maximum and average values in 2024 are shown in Figure 23. The results show that on Tuesday 6 February, the values are around the average value found in 2024. On 8 February 2024, the values are equal to the maximum values found in 2024. Like Tuesday, the values for 1 February are around the mean values.

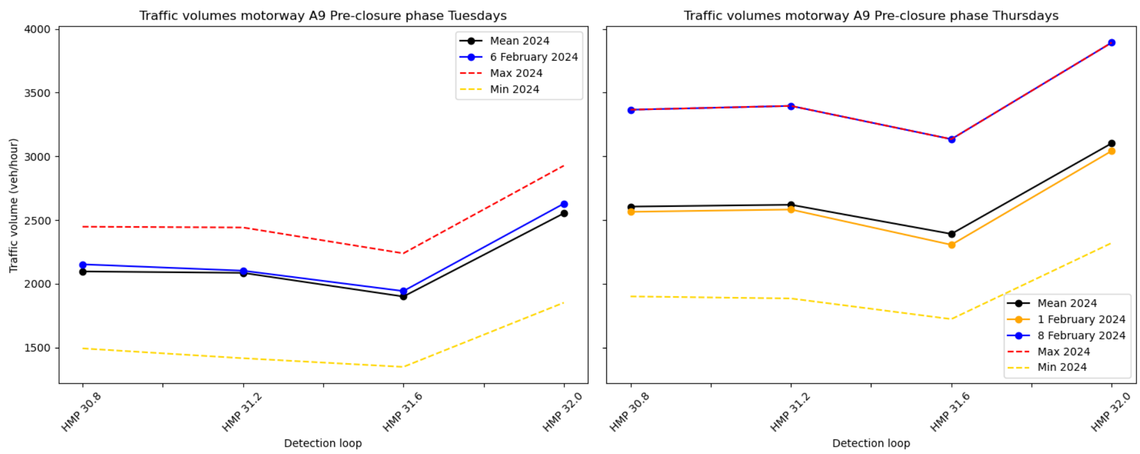

Figure 23: Pre-closure (19:00 - 20:00) traffic volumes A9 motorway

Closure phase: The closure phase is the period during which the Schipholweg is closed on the nights of 6-7 and 8-9 February 2024. There will be traffic signs on the motorway during this phase. Behaviour around the Aalsmeer exit and traffic signs will be discussed in terms of traffic volumes. For this purpose, the values for 1, 6 and 8 February for the time period 21:00 - 22:00 are shown in relation to the minimum, maximum and average values for 2024 in Figure 24.

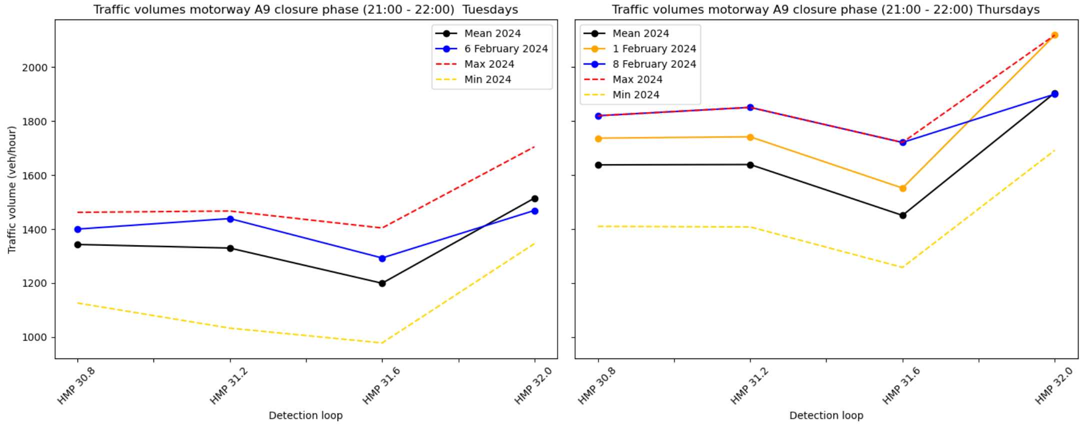

Figure 24: Closure-phase (21:00 - 22:00) traffic volumes A9 motorway

Traffic volumes around the detection loops for exits HMP 30.8 and HMP 31.2 are above average on all three days. On 8 February the measured values are equal to the maximum value found. This was also found for the pre-closure phase in Figure 23. On the days when the Schipholweg is closed, fewer vehicles use the Aalsmeer access to the A9 motorway. This results in the traffic volume at loop HMP 32.0 dropping below the mean on 6 February 2024 and reaching the mean on 8 February. On both days, the number of vehicles around this loop increases less than the average. The other periods within the closure phase show the same trends. The results for the other periods are shown in in Table 61 in Appendix H.

Exit Aalsmeer and Access Aalsmeer

By determining the difference in traffic volume between the HMP 31.2 and HMP 31.6 detection loops, it is possible to see how many vehicles use the Aalsmeer exit. These values were determined for the days on which the measurements were taken, as well as the average, minimum and maximum values for 2024. The results are shown in Figure 25. For the Aalsmeer access ramp, the number of vehicles decreases strongly on the closing days and both values are equal to the minimum value found in 2024. In addition, the number of vehicles counted on 1 February is equal to the maximum value.

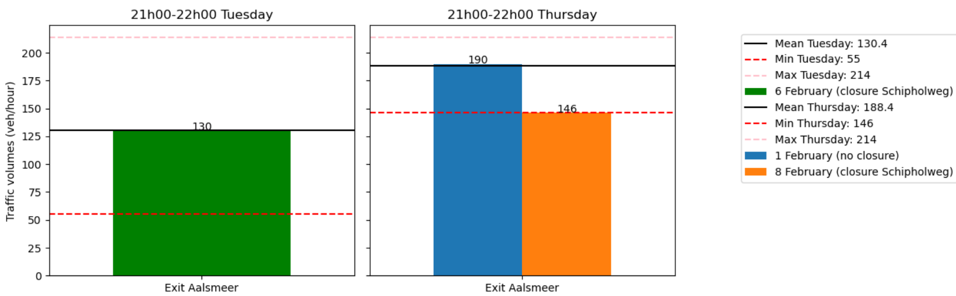

Figure 25: Closure phase (21:00 - 22:00) traffic volumes Exit Aalsmeer

The same procedure was used for the Aalsmeer exit ramp. The results can be seen in Figure 26. For the Aalsmeer access ramp, the number of vehicles decreases strongly on the closing days and both values are equal to the minimum value found in 2024. In addition, the number of vehicles counted on 1 February is equal to the maximum value.

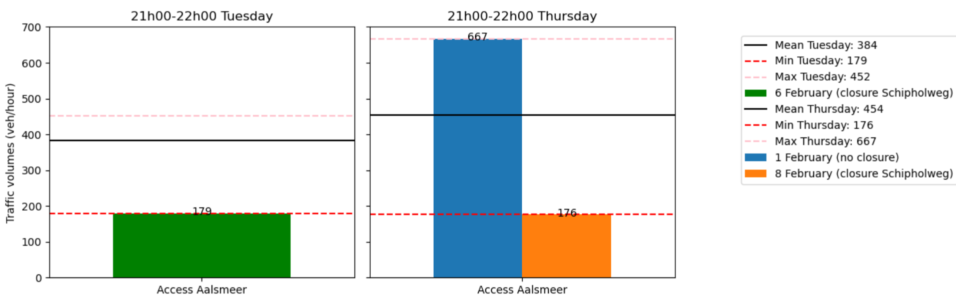

Figure 26: Closure-phase (21:00 - 22:00) traffic volumes Access Aalsmeer

The results of the other periods of the closure phase for the Aalsmeer exit and Aalsmeer access are shown in Table 11. The detection loop HMP 31.2 was not in operation from 24:00 on 7 February and therefore no vehicle numbers are detected on the exit ramp. The same trends are found for these time periods as for the time period between 21:00 and 22:00.

Table 11: Number of vehicles on exit Aalsmeer and access Aalsmeer

		Exit Aalsmeer				Access Aalsmeer			
Time	**Date**	**Vehicles**	**Mean**	**Min**	**Max**	**Vehicles**	**Mean**	**Min**	**Max**
22-23	**6-feb**	124	129	50	174	161	343	161	430
	8-feb	100	140.4	100	159	143	387.4	143	484
23-24	**6-feb**	56	63	56	72	84	304.6	84	408
	8-feb	85	73.4	68	85	98	333	98	452
24 01	**7-feb**	-	38.3	28	47	31	102.8	31	155
	9-feb	53	47.6	32	55	64	146.4	64	197
01 02	**7-feb**	-	135	24	42	12	57	12	78
	9-feb	39	38.4	26	48	30	82.8	30	116
02 03	**7-feb**	-	39	30	44	20	52.6	20	90
	9-feb	46	38	26	46	41	59.6	41	67
03 04	**7-feb**	-	95	89	98	67	53	28	73
	9-feb	113	118.8	110	126	31	56.8	31	78
04 05	**7-feb**	-	234	204	256	73	61.6	54	73
	9-feb	277	267.4	262	277	59	70.8	59	83

Post-closure phase: The post-closure phase is the period when the closure is closed and the temporary traffic signs are removed. For the night of 6-7 February, the road closure will end at 04:18 and therefore the post-closure period will be from 04:00 - 05:00. For the night of 8-9 February, the road closure ends at 03:05 and the post-closure period is from 03:00 - 04:00. The results of the motorway traffic measurements during these nights are shown in Figure 27. On 7 February the loop of HMP 31.2 did not take any measurements. In the post-closure measurements for the night of Thursday to Friday, the traffic volumes measured on 2 February correspond to the minimum value found in 2024 and those on 9 February match the maximum value.

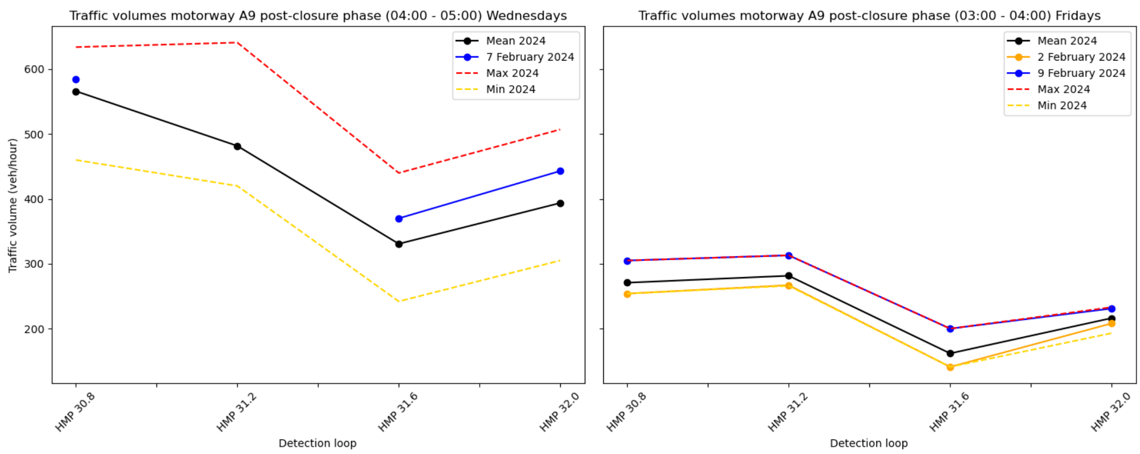

Figure 27: Post-closure phase traffic volumes A9 motorway

Exit Aalsmeer: The lower than average traffic volume at the Aalmsser exit can be explained by the fact that the road closure on 7 February does not end at a new hour. As shown in Figure 27 the HMP 31.2 detection loop did not take any measurements on 2 February during the post-closure period. Therefore, the difference between HMP 30.8 and HMP 31.6 was used to determine the number of vehicles on the exit ramp. On 2 February, the total hourly volumes were above average, but there were no disruptions on that day. On 9 February, Schipholweg was opened to traffic at 03:05. Traffic can use the exit for almost the whole hour, but the number of vehicles is still around the minimum value. However, it is not possible to conclude whether traffic on this road behaves differently as the minimum, maximum and average values are close to each other. However, both post-closure periods show the same trend of below-average vehicles.

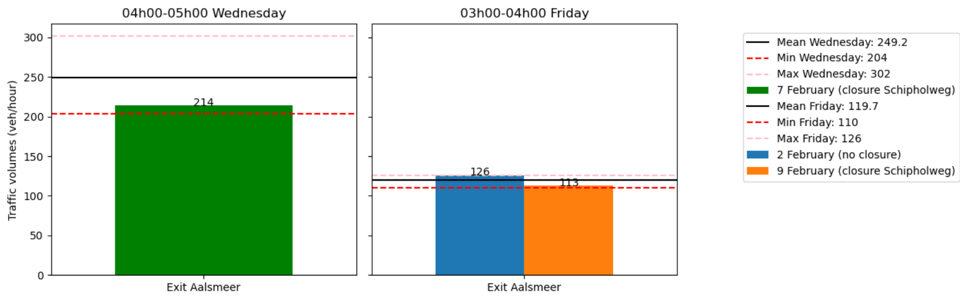

Figure 28: Post closure-phase traffic volumes exit Aalsmeer

Access Aalsmeer: During the post-closure period, the numbers on the access ramp do not show the same trends as those on the exit ramp, as shown in Figure 29. The number of vehicles using the ramp on 7 February is equal to the maximum value found. On 9 February, this value is equal to the minimum value. Therefore, the two exit days also show different behaviour.

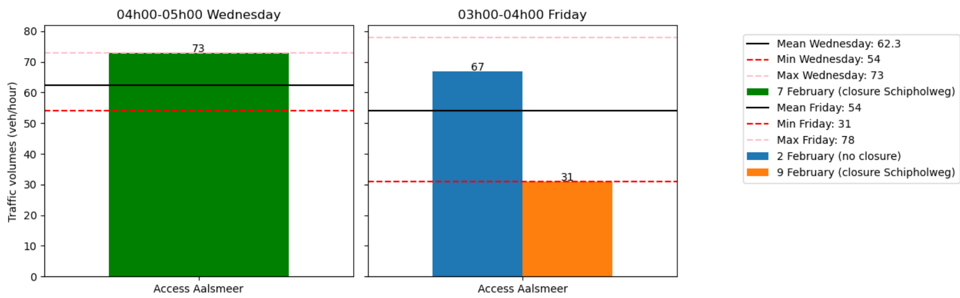

Figure 29: Post closure-phase traffic volumes Access Aalsmeer

5.2.3 Business-as-usual phase: Motorway average speed over the years

The average hourly speeds measured on the various detection loops were also determined for the motorway traffic. The averages for the years 2022, 2023 and 2024 and the minimum and maximum values for the year 2024 were used to establish a reference framework for the different phases of the closure.

Pre-closure phase: The pre-closure phase took place between 19:00 and 20:00. The average speed over the years is plotted in Figure 30. The average speed in 2024 is lower than the speeds in 2022 and 2023. In addition, the speeds in 2022 and 2023 are around the maximum average speed found in 2024. In 2024 there will be construction work on the A9 at several locations, resulting in a lower average speed [107]. For this reason, 2024 has been chosen as the reference year for differences during the Schiphol Bridge construction works.

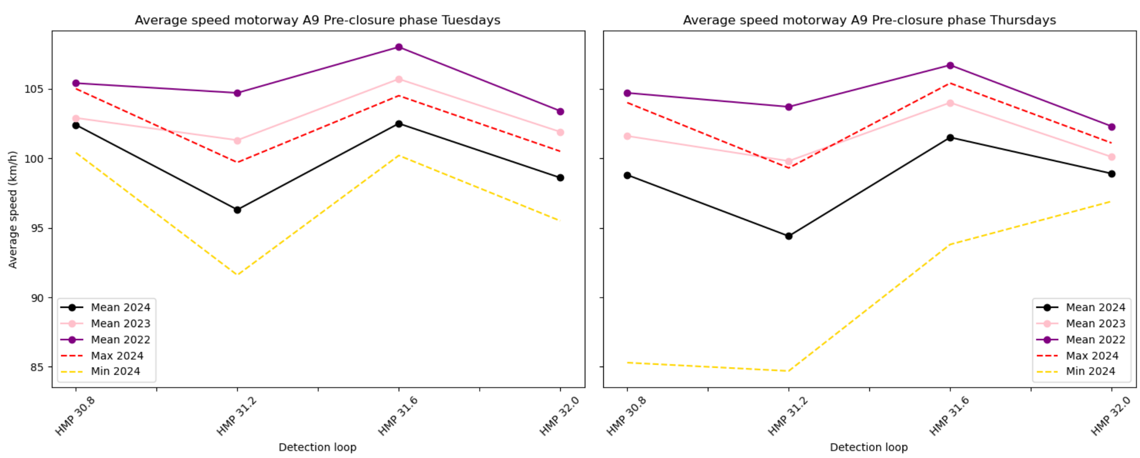

Figure 30: Pre-closure phase average speed over the years

Closure phase: An hourly reference frame has also been established for the periods when the Schipholweg is closed and the announcement and detour signs are visible on the motorway. Figure 31 shows the averages over the years for the time periods 21:00 - 22:00. It shows the same trends as in the pre-closure phase. For all periods in the closure phase, the year 2024 was also used as the reference frame. The results of these periods are shown in Table 62 in Appendix H.

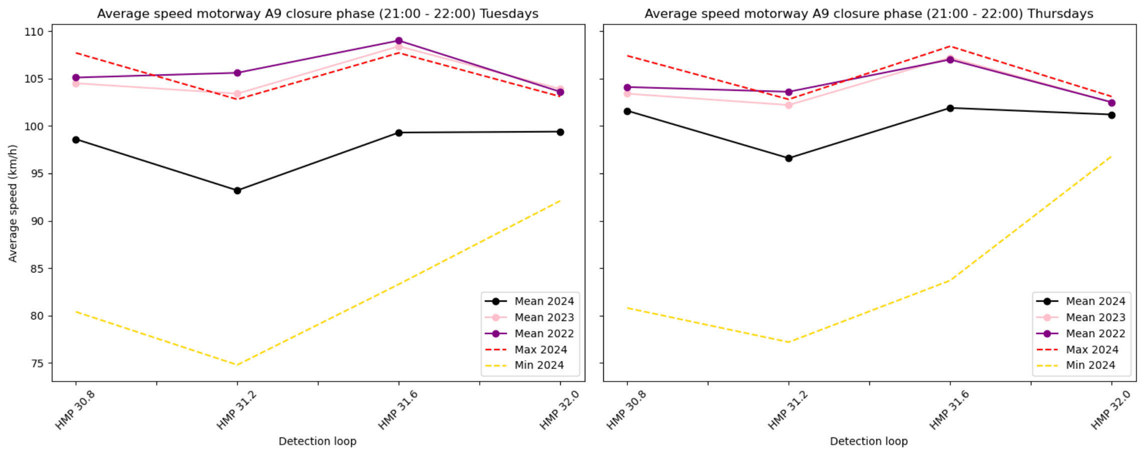

Figure 31: Closure phase average speed over the years

Post-closure phase: Finally, average speeds during the post-closure period were examined. For Tuesday-Wednesday closure, the relevant period is between 04:00 and 05:00 on Wednesday. For Thursday-Friday closure, the corresponding period is between 03:00 and 04:00 on Friday. The results are displayed in Figure 32. During these periods, the values for the years 2022 and 2023 are no longer always around the maximum value found in 2024. However, the values for these two years are generally higher than the average value in 2024. For this reason, 2024 has also been chosen as the reference year for the post-closure phase.

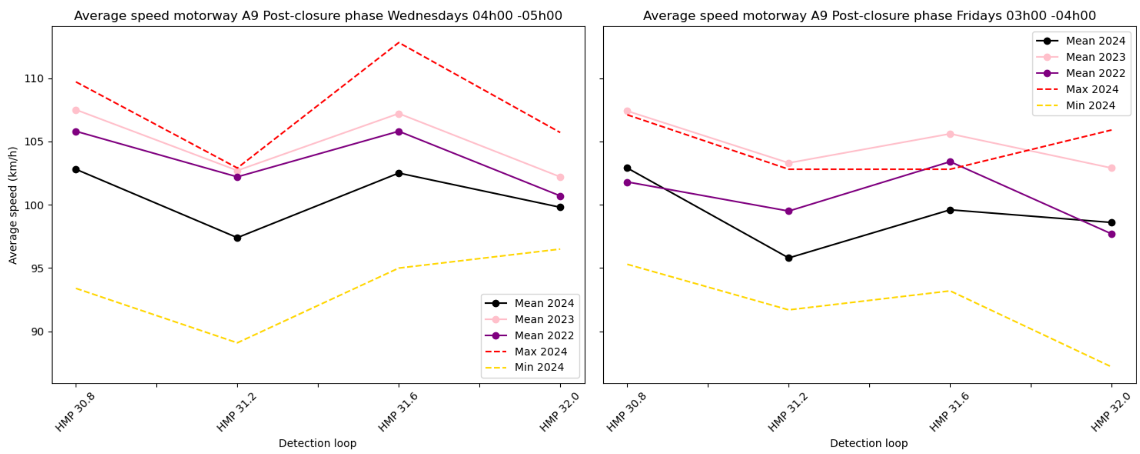

Figure 32: Post-closure phase average speed over the years

5.2.4 Motorway observations average speed

The changes in average traffic speed in the situation where temporary traffic signs are installed for the approaching closure can be compared using the established frame of reference. However, during the measurement days, the speed limit is reduced from 100 km/h to 70 km/h on part of the motorway. The reduced speed limit segment is located from HMP 29.5 to HMP 32.0 and is applied from 20:00 to 05:00 on 6 February. For 8 February the speed limit is applied from 19:00-04:00. This includes the section analysed for the A9 case study. Therefore, the average speed measured is compared with the reference frame and the new speed limit. This is done for the pre-closure, closure and post-closure periods.

Pre-closure phase: Figure 33 shows the measurements of average speed on the closure days and the reference frame. It can be seen that when the Schipholweg is closed in the evening, the average speed is around the minimum value found in 2024 on Tuesday 6 February.The measurements taken on Tuesday 6 February do not yet have the new speed limits in place. On Thursday 8 February, the new speed limits are in effect and a decrease in the average speed before the exit is observed.

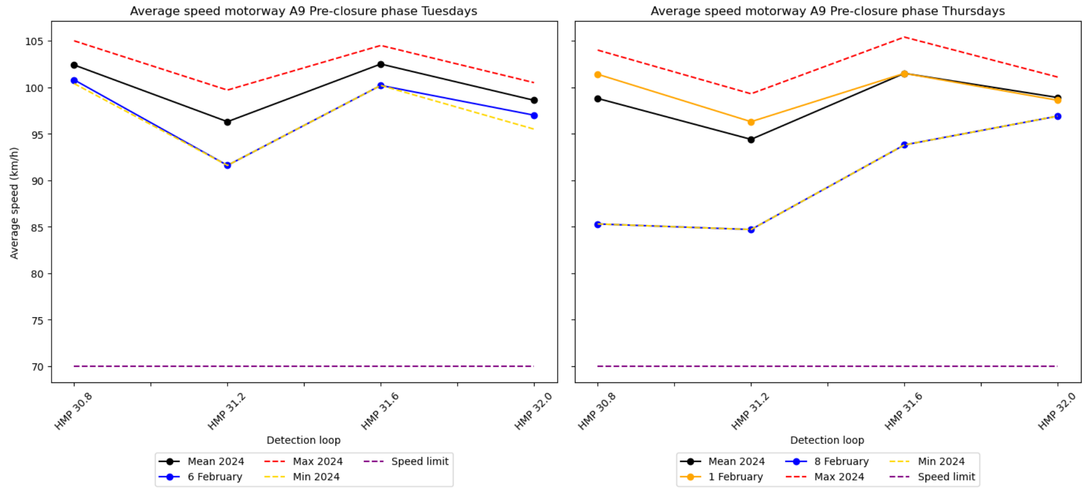

Figure 33: Pre-closure phase average speed

Closure phase: Using the same method as for the pre-closure phase, the behaviour on the motorway was determined using the average hourly speed for each time period before the closure phase. Figure 34 shows the values obtained for the period 21:00 to 22:00. The average speed around the exit shows a smaller difference towards the speed limit than in the pre-closure phase, but it is still higher. There is a decrease in speed around the exit ramp and then the average speed increases after the exit to become nearer to the average speed in 2024. This is a follow-up to the fact that the set speed limit no longer applies after the exit. The same trends in the average speed of traffic on the motorway were observed for the other periods with the closure phase, the corresponding results are given in Table 63 in Appendix H.

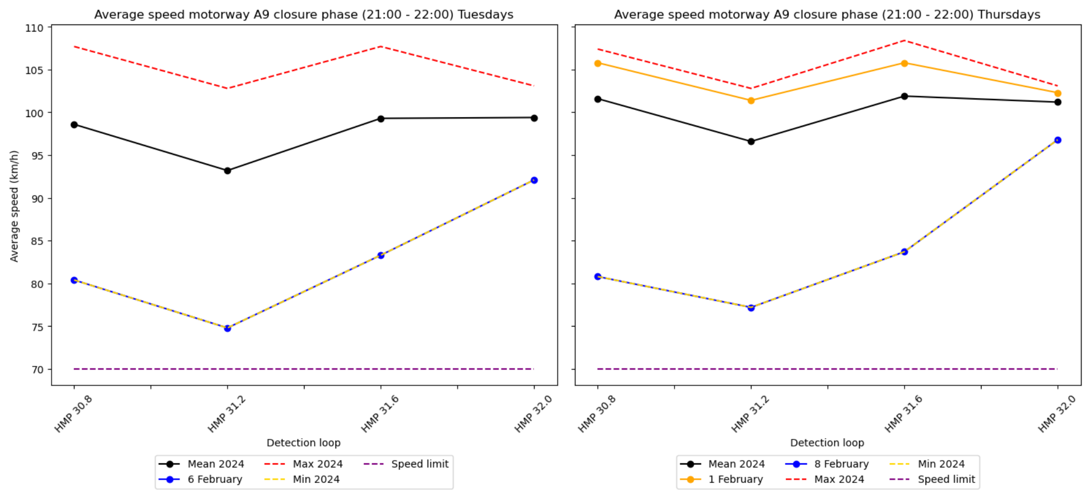

Figure 34: Closure phase average speed 21:00-22:00

Post-closure phase: The post-closure phase takes place at different times on the two closure days. There is also a difference in the duration of the post-closure phase on both days, which is the period during which the Schipholweg is open to traffic, but the associated traffic information has not yet been removed for traffic on the motorway. On 7 February, the road was opened after 18 minutes, but on 9 February it was opened at 03:05. This also means that on 9 February the accompanying signs were completely out of order earlier than on 7 February.

Different results were therefore found for the two days, which are shown in Figure 35. The average speed for the hour 04:00 to 05:00 on 7 February is still around the minimum speed found in 2024. The average speed on 9 February is higher and also increases again over the road section to above the average speed found. The difference is that on 7 February the road was opened later and the traffic signs were removed later in the hour. The speed on 9 February is higher, indicating that when temporary traffic signs are not visible, the average speed per hour increases again.

Despite the fact that the set speed limit was planned to last until 05:00, a higher speed is visible for the post-closure phases, which is closer to the average speed in 2024 than the speed limit. This would seem to indicate that the speed limit ended as soon as the works were completed, but this is not known and therefore cannot be concluded with certainty.

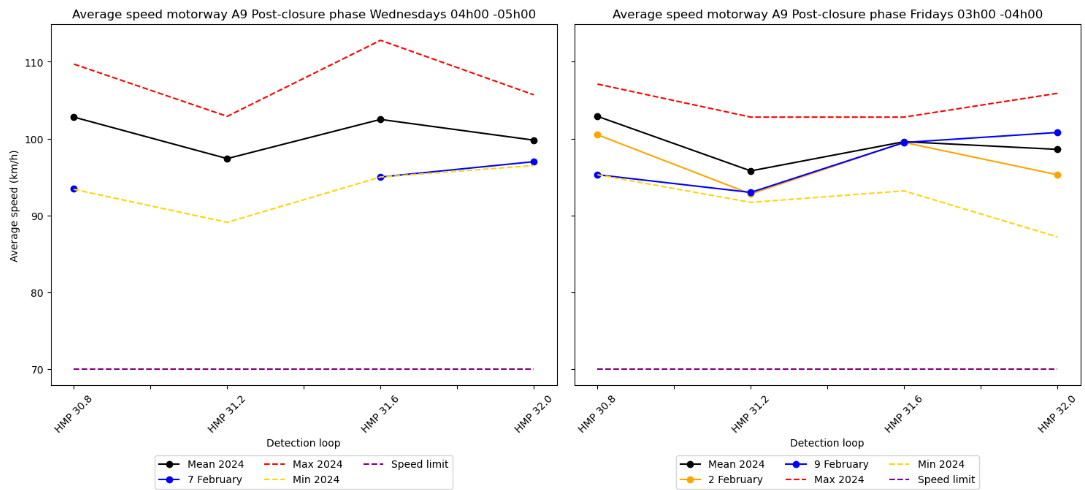

Figure 35: Post-closure phase average speed

5.2.5 Statistical chi-squared analysis

The chi-squared method is used to determine whether the behaviour on the motorway is significantly different from the expected situation. A null hypothesis is used to determine whether there is a significant difference. In the case of traffic volume, the null hypothesis is that the expected traffic volume on the different detection loops is equal to the average value found in 2024. For the average speed, a similar null hypothesis is used, except that it is the average value found for the average speed in 2024.

For each time period, measurements were taken for four different detection loops, for which the average and the values for the day in question were determined. For each hour, the chi-squared value can be calculated using the data shown in Table 12. For each hour, the degrees of freedom are equal to three, with a critical value of 9.210 for a 95% significance interval.

Table 12: Statistical chi-squared analysis input values NDW data

	Expected	**Observed**
HMP 30.8	Mean 2024	Measured value day in question
HMP 31.2	Mean 2024	Measured value day in question
HMP 31.6	Mean 2024	Measured value day in question
HMP 32.0	Mean 2024	Measured value day in question

Tuesday 6 February

For the traffic volume and average speed per hour, the chi-squared value was calculated per hour and for the whole closure period. In Table 13 the chi-squared value is calculated for the hour 21:00 - 22:00. The chi-squared value found for the period 21:00 - 22:00 is greater than the critical value. The null hypothesis is therefore rejected.

Table 13: Statistical chi-squared analysis traffic volumes 21-22 A9
Tuesday 6 February

	Expected	**Observed**	χ^2
HMP 30.8	1343	1400	2.42
HMP 31.2	1329.7	1439	8.98
HMP 31.6	1199.3	1293	7.32
HMP 32.0	1514.7	1469	1.38
		$\sum\chi^2$	20.1

For the other hours of the closure, the corresponding values have been calculated and are shown in Table 14. The chi-square value was also calculated for the entire closure phase. For the calculated chi-squared values per hour for motorway traffic, only for the periods 24 01 and 03 04 the null hypothesis is not rejected for 6 February. The total closure phase consists of 9 periods, giving a degree of freedom of 8. The corresponding critical value is 15.507. However, the calculated value also exceeds the critical value and the null hypothesis is rejected for both days. As a result, the traffic volumes show significant differences from the average values for 2024.

Table 14: Statistical chi-squared analysis Traffic volumes A9

	χ^2	
Time period	**6 February**	**8 February**
20-21	11.50	29.76
21-22	20.10	66.31
22-23	39.40	113.88
23-24	41.34	318.48
24 01	27.18	97.56
01 02	1.24	41.64
02 03	16.38	19.58
03 04	2.95	71.27
$\sum\chi^2$	160.13	758.51

The same was done for the average speed per hour, Table 15.On an hourly basis, only the average speed between 21:00 and 22:00 on 6 February differs significantly from the average speed in 2024. For 8 February this is the case for the period 21:00 - 24:00. The total value for the closing period as a whole, on the contrary, differs significantly from the expected value. However, a speed limit of 70 km/h was set on the motorway on both days. The average speed was also compared with this speed. It can be seen that for both days and each time period, the value is significantly different from 70 km/h.

Table 15: Statistical chi-squared analysis average speed A9

	χ^2 **Avg. speed**		χ^2 **Speed limit**	
Time period	**6 February**	**8 February**	**6 February**	**8 February**
20-21	7.92	3.78	14.46	27.22
21-22	10.11	11.59	11.38	15.37
22-23	9.04	10.91	12.76	19.61
23-24	7.40	10.31	19.50	19.91
24-01	3.44	5.69	22.24	21.87
01-02	5.41	4.15	18.56	23.38
02-03	3.85	2.08	20.83	22.66
03-04	3.75	0.55	20.98	42.05
$\sum\chi^2$	50.92	49.06	140.71	192.08

5.3 Route Choice Observations

ANPR cameras have been used to record traffic that has chosen to use the exit ramp and cannot continue due to the closure of the Schipholweg. This traffic should turn around at the roundabout at the end of the exit ramp to return to the motorway via the access ramp, see Figure 6. An ANPR camera is installed on both the exit and the entrance ramp, see Figure 5. The ANPR cameras record the number of vehicles per hour that pass the camera location. In addition, the recordings from the cameras are matched so that a vehicle recorded by both cameras in a given time period can be identified, subsection 2.7. This makes it possible to determine the number of vehicles that have ignored the traffic control messages. To estimate the proportion of vehicles that have turned, it is calculated how many vehicles would use the road without the closure. The following steps are considered to analyse route choices:

1. Changes in traffic during the closure of the Schipholweg compared to without the closure.
2. Number of vehicles expected on Schipholweg and exit ramp Aalsmeer without closure.
3. Closure route choices.

5.3.1 Changes in traffic volumes during closure Schipholweg Closure phase

The difference in traffic on the on- and off-ramps can be analysed by the measurements taken on Thursdays. The measurements were taken on Thursday 1 February, when none of the roads in the surrounding secondary road network of the A9 motorway were closed. On Thursday 8 February, the measurements were taken when the Schipholweg was closed from 21:00. The closing phase consists of several periods. On the Thursday measured, it lasted from 21:00 to 03:00. To analyse the differences in the closing phase, one specific time period from 21:00 to 22:00 is considered first. The trends found in this period are then compared with the other periods of the closing phase.

Thursday measurements: 21:00 - 22:00
The measurements taken between 21:00 and 22:00 on 1 February and 8 February are shown in Figure 36. There is a decrease in the number of vehicles using the Aalsmeer exit and access ramp with the closure between the two measurement days. In addition, there is an increase in the number of vehicles that are first seen on the Aalsmeer exit and later on the Aalsmeer access ramp. This shows that the decrease in the number of vehicles using the Aalsmeer access to the motorway is actually smaller than recorded. This is because vehicles turning at the roundabout are included in the count, which means that between 21:00 and 22:00 only 33 vehicles use the access to the motorway from a location on the secondary road network, in this example from the Nieuwemeerdijk.

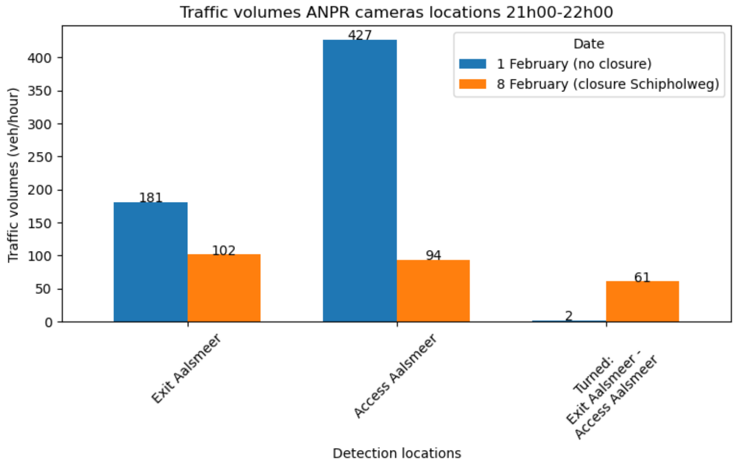

Figure 36: ANPR camera measurements 21h00-22h00

Thursday measurements: 22:00 - 03:00
The trend observed for the period 21:00 - 22:00, when the number of vehicles detected on the ramp is lower than when there is no closure, also applies to the other hours, as shown in Figure 37. It was observed that the number of vehicles seen on the ramp between 21:00 and 22:00 on 1 February is much higher than for the other hours. Furthermore, only between 02:00 and 03:00 is the number of vehicles seen on the exit ramp higher during the closure.

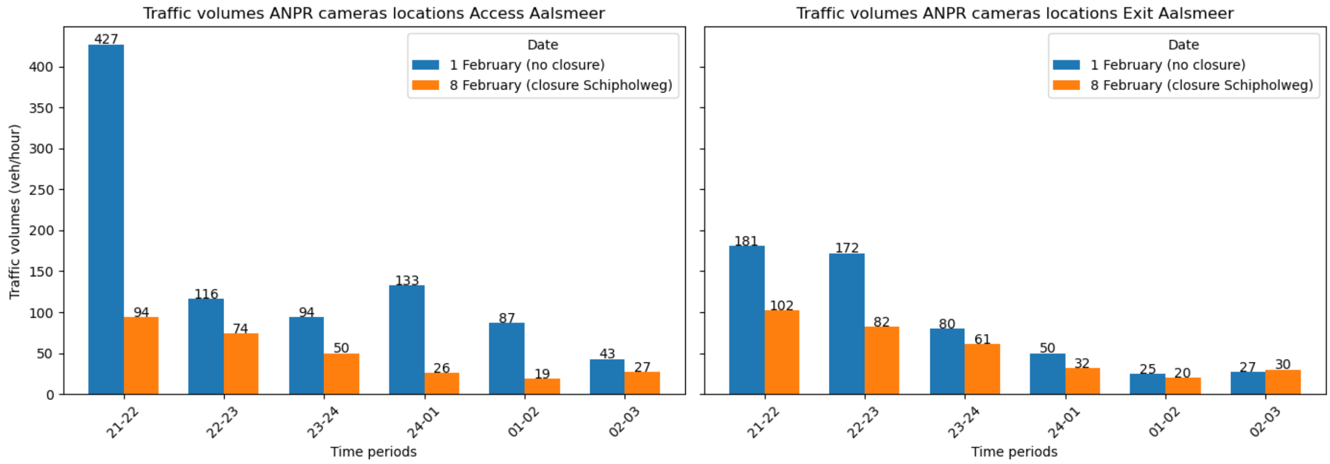

Figure 37: ANPR camera measurements Exit and Access Aalsmeer

When the Schipholweg is not closed, the number of vehicles on the access ramp consists of vehicles coming from the Schipholweg and Nieuwemeerdijk. The number of vehicles recorded on the access ramp when the Schipholweg is closed does not reflect the number of vehicles using the ramp coming from Nieuwemeerdijk, as vehicles that turn around because they cannot continue on the Schipholweg are also counted on the ramp. Figure 38 shows the measurements of vehicles that have turned back at the roundabout. It can be seen that 8 vehicles turned back between 02:00 and 03:00 on 8 February. The number of vehicles coming from the Nieuwemeerdijk is then equal to the number of vehicles counted on the access ramp, 30, minus the vehicles that turned back, so there are also fewer vehicles using the ramp between these times.

In addition, the measurements on 1 February show that when the road is not closed, it is not usual to reverse at the roundabout after taking the exit. The results of the 8 February measurements show that there is a change in behaviour when the road is closed.

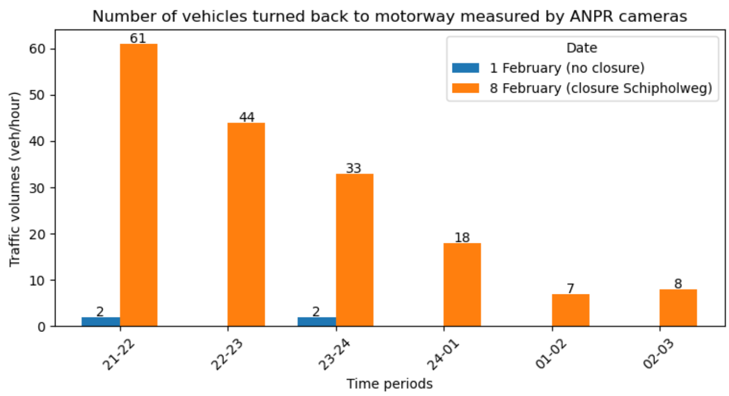

Figure 38: ANPR camera measurements Exit Aalsmeer towards Access Aalsmeer

5.3.2 Number of vehicles expected without closure

In order to determine the reaction and change in behaviour of vehicles when Schipholweg is closed, the number of vehicles expected on the access road to Schipholweg in a non-closed situation must be estimated. The number of vehicles measured on the Schipholweg when the road is not closed is not available. Therefore, the number of vehicles is estimated from available data.

The ANPR camera readings provide the following data: the number of vehicles on the ramp, the number of vehicles on the ramp that have turned and the total number of vehicles. On Tuesday 6 February and Thursday 8 February, the ANPR cameras recorded vehicle data during the closure of the Schipholweg. In addition, on Thursday 1 February, vehicle data was recorded from 21:00, including possible turnarounds, providing baseline measurements without the closure of the Schipholweg. As the measurements without closure are only available for Thursday, they can only be directly compared with the data collected on Thursday 8 February. Traffic volumes are affected by the day of the week, so the Thursday baseline cannot be used for direct comparison with the Tuesday 6 February data. However, the number of vehicles turning without a closure on Thursday 1 February can provide a reference point for understanding vehicle movements on other days of the week, such as Tuesday, when there are no closures.

On days when the Schipholweg is closed, the available data from the ANPR cameras can be used to determine the number of vehicles travelling from the motorway to Nieuwemeerdijk. The number of vehicles on Nieuwemeerdijk is equal to the number of vehicles on the exit minus the vehicles that have turned back to the motorway on the roundabout. The number of vehicles heading towards the Schipholweg on 1 February can be estimated using the linear regression method on the basis of the known number of vehicles on the exit on 1 and 8 February and the number of vehicles turning back on 8 February, the results are shown in Table 16, the corresponding linear regression plot is given in Figure 85a in subsection I.1.

Table 16: Linear regression for Number of vehicles on Schipholweg and Nieuwemeerdijk 1 February

Linear regression: Ratio of vehicles Schipholweg Nieuwemeerdijk 8 February to 1 February								
	Input				Output			
Time period	**Exit 1 Feb**	**Exit 8 Feb**	**Turned 8 Feb**	**Dijk 8 Feb**	**Schipholweg 1 February**	**Nieuwemeerdijk 1 February**	**Totaal output 1 February**	**Ratio**
21-22	181	102	61	41	110.7	71.3	182	60.8%
22-23	172	82	44	38	104.9	68	172.9	60.7%
23-24	80	61	33	28	45.1	34.9	80	56.4%
24-01	50	32	18	13	25.6	24	49.6	51.6%
01-02	25	20	7	12	9.3	15	24.3	38.3%
02-03	27	30	8	22	10.6	15.8	26.4	40.2%

However, it is not possible to estimate the expected values for Nieuwemeersdijk and Schipholweg in the absence of closure on 1 and 6 February on the basis of the data collected. For this reason, the values obtained using the NDW data from the detection loops were used. Using the motorway traffic volumes for the exit ramp, the HMP 31.2 detection loop and the values found on the exit ramp on the days without closure, it is possible to calculate how many vehicles are expected to be on the exit ramp based on the motorway traffic volumes. While it is known how many vehicles were counted on the exit ramp when there was a closure, this method can be used to estimate the number of vehicles that would use the exit ramp without a closure. On this basis it is possible to compare the situation with the closure with what would happen if the road were not closed.

Three different estimates were used to determine the expected value of vehicles at Exit Aalsmeer. Firstly, the values were based on the average value at the HMP 31.2 detection loop and the Aalsmeer exit on the day in question and the values measured at the detection loop HMP 31.2 detection loop on the days of the closure. In addition, this was done one and two weeks before the day in question in comparison with the traffic volume at the detection loop on the day in question. The expected values are based on the input variables shown in Table 17 for Tuesday and based on the input variables shown in Table 18 for Thursday. In addition, the exit ANPR camera measurements were available from 21:00. Therefore, the number of vehicles on the exit ramp on 8 February is determined using linear regression, also based on the ANPR camera counts. As a result, the number of vehicles expected on the exit ramp can be determined.

Table 17: Linear regression input values Tuesday

Linear regression Input Tuesday							
	HMP 31.2				Exit Aalsmeer		
Time period	**Mean 2024***	**23 Jan**	**30 Jan**	**6 Feb**	**Mean 2024***	**23 Jan**	**30 Jan**
19-20	2085.9	2442	2223	2103	181	203	236
20-21	1493.7	1543	1732	1565	141	138	187
21-22	1329.7	1375	1467	1439	150.8	146	214
22-23	1064.7	1052	1218	1198	125.6	143	174
23-24	648.7	540	881	738	65	61	72
24-01	303	304	313	351	35.8	27	37
01-02	161.4	174	153	169	24.4	33	27
02-03	119.7	129	119	101	30.4	24	30
03-04	218.6	225	201	213	93.4	94	86
04-05	552.9	475	551	530	244.4	222	253

*Mean 2024: January - March

Table 18: Linear regression input values Thursday

Linear regression Input Thursday								
	HMP 31.2				Exit Aalsmeer			
Time period	**Mean 2024***	**25 Jan**	**1 Feb**	**8 Feb**	**Mean 2024***	**25 Jan**	**1 Feb**	**ANPR 1 Feb**
19-20	2620.3	2615	2583	3396	222.4	242	277	
20-21	1817.7	1950	1884	1904	184.6	178	192	
21-22	1674.5	1741	1742	1851	188.4	214	190	181
22-23	1175.7	1429	1193	1423	146.6	159	151	172
23-24	860.8	858	840	1170	70.6	74	70	80
24-01	338	397	342	337	49.2	47	55	50
01-02	169.5	229	170	180	38	48	26	25
02-03	148.5	135	152	131	37.6	42	26	27
03-04	256	277	243	305	121	122	126	123

*Mean 2024: January - March

Expectations of the number of vehicles on the exit ramp via linear regression have been determined using several approaches, the corresponding linear regression plots are shown in subsection I.1. The results can be seen at Table 19. If the values are based on averages, this means that the input variables are the average traffic volumes of HMP 31.2 and exit Aalsmeer for the year 2024 and the day in question. If the values are based on values from a specific day, for example, 25 January. In that case, this means that the input variables are the traffic volumes found for HMP 31.2 and exit Aalsmeer on that day and the values found on the motorway for the day in question.

Table 19: Number of vehicles expected on exit ramp Aalsmeer by linear regression

Estimated vehicles on exit ramp Aalsmeer											
Input	**Estimated Date**	**19-20**	**20-21**	**21-22**	**22-23**	**23-24**	**24-01**	**01-02**	**02-03**	**03-04**	**04-05**
Mean Thursday	**1 February**	234.7	182.8	172.2	131.4	105.2	68.2	55.4	54.1	60.9	
25 January		244.1	189.1	177.9	134.8	107	67.8	54.3	52.9	60	
Mean Thursday	**8 February**	295	184.3	180.3	148.5	129.7	67.8	56.2	52.5	65.5	
25 January		308.1	190.7	186.5	152.9	132.9	67.4	55.1	51.2	64.9	
1 February		336.6	203.9	199.3	161.2	138.7	64.7	50.7	46.4	61.8	
ANPR				200.2	161.7	139	64.2	50.1	45.7	61.3	
Mean Tuesday	**6 February**	196.1	159.3	150.6	134.2	102.7	76.2	63.8	59.1	66.8	88.5
23 January		191.2	155.7	147.4	131.5	101.2	75.7	63.7	59.2	66.6	87.5
31 January		238.7	193.1	182.4	161.9	122.9	90	74.6	68.8	78.3	105.2

The values found for the exit in Table 19 show that different input values also lead to different results. For Thursdays, the average values for the hours up to 24:00 give lower values than the other approaches, but after 24:00 the values are closer to the other values. Furthermore, the values for the linear regression using 1 February up to 24:00 are the highest values compared to the other approaches. For Tuesdays, the values obtained using 31 January as an input variable for the linear regression method are the highest values for each time period for the expected values for Tuesdays. The expected values from linear regression were compared with the actual measured values from the NDW and ANPR cameras measured on 1 February. The results are shown in Table 20. The linear regression approaches underestimate the values between 19:00 and 23:00 and overestimate the number of vehicles between 23:00 and 03:00.

Table 20: Number of vehicles expected on Exit ramp Aalsmeer by linear regression

Estimated vehicles versus measured Exit Aalsmeer 1 February									
	19-20	**20-21**	**21-22**	**22-23**	**23-24**	**24-01**	**01-02**	**02-03**	**03-04**
Estimates 1 Feb - mean	234.7	182.8	172.2	131.4	105.2	68.2	55.4	54.1	60.9
Estimates 1 Feb - 25 Jan	244.1	189.1	177.9	134.8	107	67.8	54.3	52.9	60
NDW data	277	192	190	151	70	55	26	26	126
ANPR camera			181	172	80	50	25	27	123

With the calculated expected numbers on the exit ramp, it is possible to make an expected prediction of the number of vehicles using Schipholweg after leaving the exit ramp. Table 16 shows the percentage of vehicles detected on the exit ramp that used Schipholweg on 1 February. Using these ratios and the values found for the Aalsmeer exit, the number of vehicles expected on the other days can be determined. In Table 21 the proportion of vehicles using the Schipholweg is shown in accordance with the ratios found.

Table 21: Number of vehicles expected on Schipholweg by linear regression and ratio

Estimated vehicles on Schipholweg							
Input	**Estimated Date**	**21-22**	**22-23**	**23-24**	**24-01**	**01-02**	**02-03**
Ratio Schipholweg		60.8%	60.7%	56.4%	51.6%	38.3%	40.2%
Mean Thursday	**1 February**	104.7	79.8	59.3	35.2	21.2	21.7
25 January		108.2	81.8	60.3	35.0	20.8	21.3
Mean Thursday	**8 February**	109.6	90.1	73.2	35.0	21.5	21.1
25 January		113.4	92.8	75.0	34.8	21.1	20.6
1 February		121.2	97.8	78.2	33.4	19.4	18.7
ANPR		121.7	98.2	78.4	33.1	19.2	18.4
Mean Tuesday	**6 February**	91.6	81.5	57.9	39.3	24.4	23.8
23 January		89.6	79.8	57.1	39.1	24.4	23.8
31 January		110.9	98.3	69.3	46.4	28.6	27.7

5.3.3 Closure route choices

On 6 and 8 February, the ANPR cameras recorded the number of vehicles using the Aalsmeer access and exit ramps and the number of vehicles registered by both ANPR cameras within 2 minutes. The Schipholweg is closed on these days. Nieuwemeerdijk is accessible for traffic, but this road is not an alternative route for traffic heading towards the Schipholweg. Therefore, the overlapping measurements of the vehicles by the cameras show that these vehicles were heading towards Schipholweg. There are traffic signs on the motorway indicating that the Schipholweg is closed and that there is a detour to direct traffic in the right direction. However, vehicles reversing at the roundabout due to the closure do not follow these signs. Based on the measurements from the ANPR cameras and the expected vehicles on the exit ramp when there is no closure defined in subsubsection 5.3.2, the traffic that does not respect the associated static traffic signs is estimated.

Pre-closure phase: The pre-closure phase was not included in the analysis because there is no data on the number of vehicles expected on the exit ramp under normal conditions on both closure days, nor on the number of vehicles heading towards the Schipholweg during this period, as the road was not closed.

Closure phase: The ANPR camera results show that vehicles on the roundabout turned back towards the motorway. Figure 39 shows the results for both closure days. Turning vehicles are shown as Exit Aalsmeer - Access Aalsmeer. It can be seen that every hour during the closure, there is a proportion of vehicles that use Exit Aalsmeer to return to the motorway via Access Aalsmeer. Due to the temporary traffic measures on the A9 motorway, the number of vehicles on the exit does not reflect the number of vehicles that would normally use the Schipholweg without the closure.

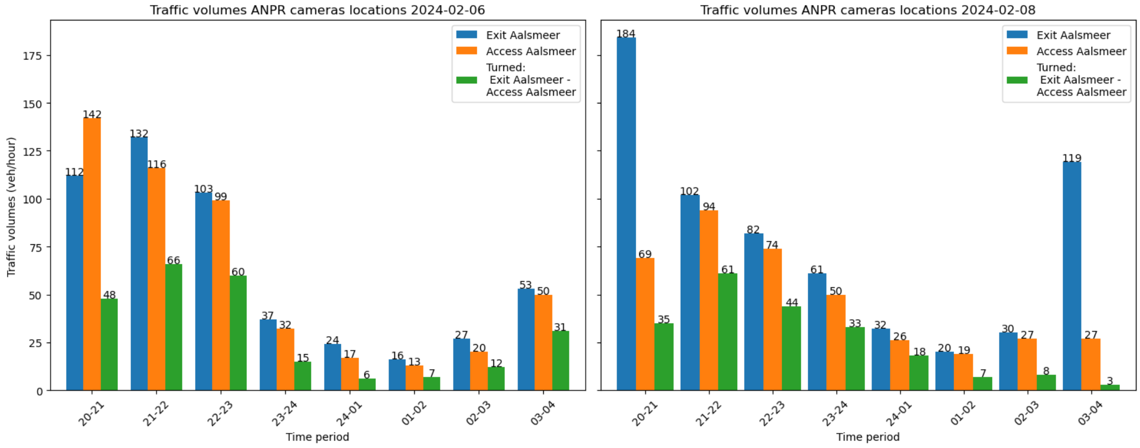

Figure 39: ANPR camera measurements Thursday 6 and 8 February 2024

For Tuesday 6 February and Thursday 8 February, the number of vehicles that turned around because they did not follow the measures and could not continue on the road was counted with ANPR cameras. In the previous section, the linear regression method was used to make a rough estimate of how many vehicles would have wanted to use the exit ramp Aalsmeer and the Schipholweg under normal conditions, based on the available data. The results from Table 16 and Table 19 were used to estimate the proportion of vehicles that did not follow the temporary traffic measures by taking the Aalsmeer exit anyway. For an estimation of the actual number of vehicles that wanted to use the Schipholweg, additional ANPR cameras would have been needed to determine which vehicles from the motorway before the Aalsmeer exit used the detour or other possible alternative routes to get in the right direction.

In order to determine the proportion of vehicles that did not follow the traffic measures for the available data, two different ratios are calculated. The first corresponds to a minimum value of vehicles not following the measurements. This ratio is determined by comparing the number of vehicles measured by the ANPR cameras that have turned at the bottom of the exit with the number of vehicles expected at the Aalsmeer exit, given in Table 19. This ratio does not take into account that vehicles may also be heading towards Nieuwemeerdijk. To calculate an expected ratio for this purpose the numbers from Table 21 are used. These are the expected number of vehicles that are heading towards the Schipholweg, based on the expected number of vehicles on the exit road and the ratio found on 1 February heading towards the Schipholweg.

Ratio of non-compliant vehicles to number of vehicles on exit ramp Aalsmeer

First, the minimum ratio of non-compliant vehicles is determined based on the different linear regression approaches for both days (6 February and 8 February). The approach used was to compare the values on the day in question with the average value found on that day, two weeks before and one week before. The results of 6 February are shown in Table 22.

Table 22: Percentage vehicles does not respect traffic measures Tuesday

Proportion vehicles not respecting temporary traffic measures compared to expected vehicles on Exit Aalsmeer 6 February 2024								
Linear Regression Approach	**20-21**	**21-22**	**22-23**	**23-24**	**24-01**	**01-02**	**02-03**	**03-04**
Number of vehicles turned	48	66	60	15	6	7	12	31
Mean Tuesday	30.1%	43.8%	44.7%	14.6%	7.9%	11.0%	20.3%	46.4%
23 January	30.8%	44.8%	45.6%	14.8%	7.9%	11.0%	20.3%	46.5%
31 January	24.9%	36.2%	37.1%	12.2%	6.7%	9.4%	17.4%	39.6%

The percentages show that the number of vehicles that do not respect the measurement instructions varies from hour to hour and that the values for the previous week's approach are lower than the other two approaches. Until midnight, the non-compliance rates range from 12.2% to 45.6%. After midnight, the percentages decrease in the first hour between 00:00 and 01:00 and then increase again hour by hour.

The percentage of vehicles not respecting the temporary traffic signs on Thursday 8 February based on the linear regression approaches including the values based on the measurements of 1 February are shown in Table 23. For the closure on

Thursday 8 February (from 21:00), the percentages up to midnight of not complying are between 27.2% and 33.8%. After midnight, the percentages decrease less than for the night of 6-7 February and even increase for the first hour. The road work ended at 03:05, therefore the percentages for the period between 03:00 and 04:00 are much lower, as the road is open again (no need to turn around).

Table 23: Proportion vehicles does not respect traffic measures Thursday

Proportion vehicles not respecting temporary traffic measures Compared to exit Aalsmeer 8 February 2024								
Linear Regression Approach	**20-21**	**21-22**	**22-23**	**23-24**	**24-01**	**01-02**	**02-03**	**03-04**
Number of vehicles turned	35	61	44	33	18	7	8	3
Mean Thursday	19.0%	33.8%	29.6%	25.4%	26.5%	12.5%	15.2%	4.6%
25 January	18.4%	32.7%	28.8%	24.8%	26.7%	12.7%	15.6%	4.6%
1 February	17.2%	30.6%	27.3%	23.8%	27.8%	13.8%	17.2%	4.9%
ANPR camera 1 Feb	-	30.5%	27.2%	23.7%	28.0%	14.0%	17.5%	-

Ratio of non-compliant vehicles to the expected number of vehicles on Schipholweg
In addition to the minimum ratio of vehicles not following the detour, a ratio was calculated based on the observed value of vehicles entering Schipholweg from the exit. The found ratios of vehicles not complying with the measures to the number of vehicles expected on the Schipholweg for the night of 6-7 February are shown in Table 24. The percentages are higher than the values found in relation to the number on the exit ramp. The higher percentages are due to the fact that a division has been made by including the possibility of going towards the Nieuwemeerdijk. The percentages found between 21:00 and 23:00 are higher than for the other periods. In addition, the percentages on 31 January are lower than for the other linear regression approaches. This is due to the higher number of vehicles on the exit ramp on 31 March than on the other days.

Table 24: Proportion vehicles does not respect traffic measures versus Schipholweg

Proportion vehicles not respecting temporary traffic measures versus expected Schipholweg 6-7 February 2024						
Estimated Linear Regression Approach	**21-22**	**22-23**	**23-24**	**24-01**	**01-02**	**02-03**
Mean Tuesday	72.1%	73.7%	25.9%	15.3%	28.6%	50.5%
23 January	73.6%	75.2%	26.3%	15.4%	28.7%	50.4%
31 January	59.5%	61.1%	21.6%	12.9%	24.5%	43.4%

The proportions of non-compliant vehicles for Thursday 8 February are determined in the same way and given in Table 25. In addition to comparing the number of vehicles in the direction of Schipholweg with the number of vehicles at the Aalsmeer exit using the linear regression approaches, a comparison was also made with the number of vehicles turning in the direction of Schipholweg on Thursday 1 February. In the results of the NDW data, where the traffic volumes were determined and compared, it can be seen that the values for 1 February are around the average values for Thursday on the motorway and the exit, subsubsection 5.2.2. For this reason, this value was used as an indication of the vehicles that would use the Schipholweg under normal conditions on a Thursday night.

Table 25: Proportion vehicles does not respect traffic measures versus Schipholweg

Proportion vehicles not respecting temporary traffic measures versus expected Schipholweg 8 February 2024						
Estimated Linear Regression Approach	**21-22**	**22-23**	**23-24**	**24-01**	**01-02**	**02-03**
Mean Thursday	55.6%	48.8%	45.1%	51.5%	32.5%	37.9%
25 january	53.8%	47.4%	44.0%	51.8%	33.2%	38.9%
1 February	50.3%	45.0%	42.2%	53.9%	36.0%	42.9%
ANPR 1 February	50.1%	44.8%	42.1%	54.3%	36.5%	43.5%
Schipholweg 1 February	55.1%	41.9%	73.2%	70.3%	75.3%	75.5%

The results show that between 32.5% and 55.6% of the expected vehicles heading towards Schipholweg do not follow the measures. The night of 1st to 2nd February was a night where the numbers were around the 2024 average on the motorway, but when comparing the values with the other approaches, the percentages based on the number of vehicles on the Schipholweg on 1 February are higher between 23:00 and 03:00 than on the other days. The values found then range from 41.9% to 75.5%. The percentages compared to the results found on Tuesdays are lower on Thursdays up to 23:00, but higher between 23:00 and 02:00.

Ranges of ratio of non-compliant vehicles
The values obtained can be used to construct a range for the different time periods of ratios that do not follow traffic measures. The ranges are determined from the minimum and maximum values found using the different approaches. The results are shown in Table 26.

Table 26: Range ratios not complying with traffic measures

Day	**Tuesday**			**Thursday**			**Total**
Time	**Range Ratio Exit Aalsmeer**	**Range Ratio Schipholweg**	**Total Range**	**Range Ratio Exit Aalsmeer**	**Range Ratio Schipholweg**	**Total Range**	**Total Range**
21-22	36.2 - 44.8%	59.5 - 73.6%	36.2 - 73.6%	30.5 - 33.8%	50.1 - 55.5%	30.5 - 55.5%	30.5 - 73.6%
22-23	37.1 - 45.6%	61.1 - 75.2%	37.1 - 75.2%	27.2 - 29.6%	41.9 - 48.8%	27.2 - 48.8%	27.2 - 75.2%
23-24	12.2 - 14.8%	21.6 - 26.3%	12.2 - 26.3%	23.7 - 25.4%	42.1 - 73.2%	23.7 - 73.2%	12.2 - 73.2%
24-01	6.7 - 7.9%	12.9 - 15.4%	6.7 - 15.4%	26.5 - 28%	51.5 - 70.3%	26.5 - 70.3%	6.7 - 70.3%
01-02	9.4 - 11%	24.5 - 28.6%	9.4 - 28.6%	12.5 - 14%	32.5 - 75.3%	12.5 - 75.3%	9.4 - 75.3%
02-03	17.4 - 20.3%	43.4 - 50.5%	17.4 - 50.5%	15.2 - 17.5%	37.9 - 75.5%	15.2 - 75.5%	17.4- 75.5%

Post-closure phase: After the closure, the road will be reopened to traffic. This will allow traffic to use the Schipholweg again after a certain period of time, which means that vehicles using the Schipholweg exit will no longer be forced to turn back onto the motorway. However, during the period when the road is still closed, vehicles will continue to turn around. The percentages for this are also calculated for the closure phase. However, these give a distorted picture because the road was partially reopened to traffic. The results are given in Table 27.

Table 27: Proportion vehicles does not respect traffic measurements Post-closure phase

	6 February	**8 February**
Number of vehicles turned	17	3
Mean	4.6%	19.2%
23 January	4.6%	-
25 January	-	19.4 %
31 January	4.9%	-
1 February	-	16.2%

5.3.4 Statistical chi-squared analysis

Statistical analysis using the Chi-square method was used to determine the significance of the route choice observations. The null hypothesis was first formulated to assess whether the observations were significantly different from expectations. In the context of the road closure and associated traffic measures, the null hypothesis states that vehicles will follow the traffic information provided. Specifically, the null hypothesis assumes that no vehicles will be observed reversing at the exit. This hypothesis is based on the intention that the measures implemented and the signs placed effectively divert traffic.

Based on the A9 case study, two possible decisions are considered. Decision 1 is to follow the signs and pass the exit. Decision 2 is not to follow the signs and take the exit. For each hour, the expected and actual numbers include the combinations, shown in Table 28.

Table 28: Statistical chi-squared analysis input values

	Expected	**Observed**
Decision 1	Expected value based on Linear regression	Expected minus Vehicles turned around at exit
Decision 2	0	Vehicles turned around at exit

Because of the null hypothesis, the expected number of vehicles for Decision 2 is zero. However, an expected value of zero causes the chi-square value to go to infinity. Consequently, it is tested here whether the statistical situation is significantly different from the null hypothesis on the basis of decision 1. The implication of this choice is that it is not possible to determine per hour whether it is significantly different from the null hypothesis, as the degree of freedom is zero in this setting. However, it is possible to determine whether the values are significantly different over several time periods. For this purpose, chi-squared values were calculated for the closure periods.

Tuesday 6 February

The closure phase on Tuesday 6 February takes place between 20:00 and 4:00. The linear regression method was applied to three different approaches to determine the expected values. Chi-square values were determined based on these approaches and are presented in Table 29. The closure phase consists of 8 separate time periods, giving 7 degrees of freedom for this analysis. For a 95% significance level, p-value is 0.05, this gives a critical chi-squared value of 14.067. If the Chi-square value found is higher than the critical value, the results differ significantly from the null hypothesis. In this case, this is the case for all the Chi-squared values found. This means that the null hypothesis that all vehicles make the choice to follow the temporary traffic measures is rejected.

Table 29: Statistical chi-squared analysis Tuesday 6 February 2024

	χ^2		
Time period	**Mean**	**23 Jan**	**31 Jan**
20-21	14.46	12.66	34.65
21-22	28.92	26.76	52.44
22-23	26.83	24.97	47.51
23-24	2.19	1.80	10.08
24-01	0.47	0.40	4.36
01-02	0.77	0.75	4.25
02-03	2.44	2.47	6.84
03-04	14.39	14.24	23.07
$\sum\chi^2$	90.47	84.05	183.19

Thursday 8 February

For the number of vehicles found in the closure phase on Thursday 8 February, the same steps were followed as for Tuesday 6 February. On 8 February, the closure phase took place between 21:00 and 03:00. Therefore, six different time periods were analysed. The degree of freedom is then equal to 5, with an associated critical value for the 95% significance level of 11.070. The expected volume of vehicles on Thursday 8 February was determined using four linear regression approaches. The corresponding chi-squared values for all approaches and observations are shown in Table 30. The sum of all chi-squared values in the closing phase for the approaches is higher than the critical chi-squared value. This means that the null hypothesis that everyone follows the information is also rejected for Thursday 8 February.

Table 30: Statistical chi-squared analysis Thursday 8 February

	χ^2			
Time period	**Mean**	**25 Jan**	**1 Feb**	**ANPR**
21-22	20.63783	19.95174	18.67035	18.58641
22-23	13.03704	12.66187	12.00993	11.97279
23-24	8.396299	8.194131	7.851478	7.834532
24 01	4.778761	4.807122	5.007728	5.046729
01 02	0.902394	0.889292	0.966469	0.978044
02 03	1.20983	1.25	1.37931	1.400438
$\sum\chi^2$	48.96215	47.75416	45.88526	45.96576

5.4 Results case study A9

For the case study at the A9 motorway exit in Aalsmeer, the impact of temporary traffic measures on the motorway and the closure of the Schipholweg to the secondary road network was analysed. First, using the NDW data from the detection loops, the traffic volume on the closure days was compared to the average traffic volume in 2024. In addition, the average speed per hour was compared to the average. Secondly, ANPR camera measurements were used to see which vehicles used the exit despite the measures and returned to the motorway within two minutes.

The closure was carried out on the night of 6-7 February and on the night of 8-9 February. Both nights were divided into three distinct phases: the pre-closure phase, the closure phase and the post-closure phase. Based on the three different phases, the behaviour around the closure and the informative temporary traffic signs were analysed. The results of vehicles complying the traffic signs ranges are shown in Figure 40.

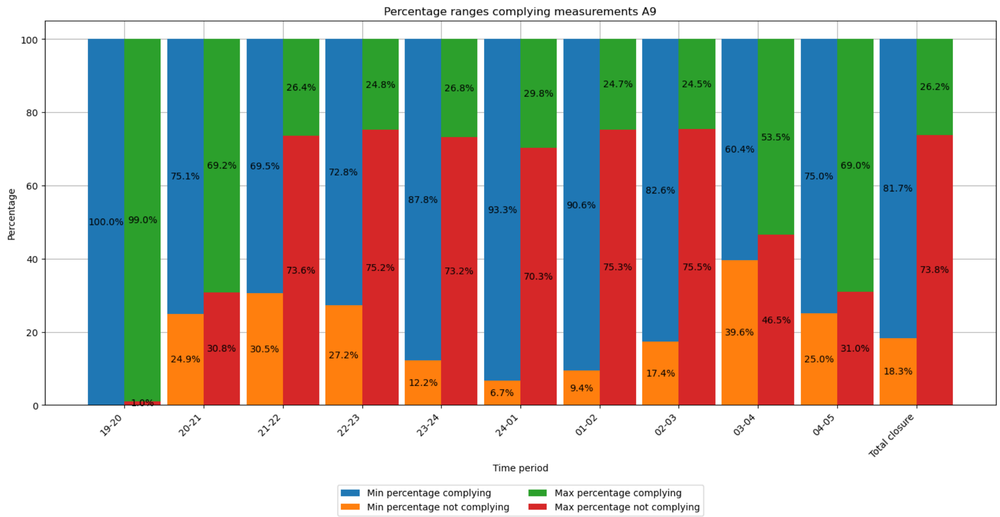

Figure 40: Percentage ranges complying measurements combination of the nights of 6-7 and 8-9 February A9
Min percentage: percentage of vehicles compared to expected vehicles exit Aalsmeer
Max percentage: percentage of vehicles compared to expected vehicles Schipholweg
Total closure: percentage of vehicles complying with measures between 21:00 - 03:00

During the pre-closure phase, there is no unusual traffic behaviour in terms of route choice. No vehicles are reversing at the roundabout, which is not necessary as the Schipholweg is still open to traffic during the pre-closure phase. The pre-closure for the night of 8-9 February will end at 20:28. As a result, two periods are visible between 20:00 and 21:00. However, the available data did not distinguish between the pre-closure and closure phases during this period. Therefore, this hour shows different results than the pre-closure period between 19:00 and 20:00 in terms of route decisions. On 8 February there are vehicles turning around between 20:00 and 21:00. In the pre-closure phase, a decrease in the average hourly speed is observed for both nights. However, there are also traffic measures on the motorway in the form of a lower speed limit, which should be the main reason for the speed reduction.

The closure phase is the period during which the Schipholweg is closed to traffic. During the periods within this phase, it has been recorded that the traffic volume on the motorway is higher than average on the nights of 8 and 9 February.

The number of vehicles on the access and exit ramp during the night is not above average. The number of vehicles on the Aalsmeer exit and the Aalsmeer access ramp will decrease due to the closure of the Schipholweg for all hours within the closure phase, and for both nights are similar to the minimum value found in 2024. The analysis of the measurements with the ANPR cameras on the entry and exit ramps shows a significant deviation from the null hypothesis. The null hypothesis was that in a normal situation, vehicles that want to go to Schipholweg do not use the exit ramp when the Schipholweg is closed. However, the measurements show that a significant proportion of vehicles have to turn around at the roundabout to return to the motorway. Throughout the entire closure period on both nights, the percentage of vehicles that do not comply with the measures and still use the exit ranges from 18.3% to 73.8%. This range is determined by comparing the number of vehicles that turned at the roundabout due to the closure of the Schipholweg with the expected number of vehicles on the exit ramp (18.3%) and further specifying the number of vehicles from this group that were expected to head towards the Schipholweg (73.8%). Therefore, 18.3% can be considered the minimum percentage of vehicles not complying with the measures during the closure. This percentage should be taken into account when assessing the impact on the total traffic on the exit ramp, as it shows how many vehicles ignore the measures compared to the total expected traffic on the exit ramp without closure. The 73.8% gives a more accurate indication of the number of vehicles that do not follow the detour signs, which equals to 18.3% of the expected traffic on the exit ramp.

The post-closure phase takes place after the Schipholweg has been reopened to traffic and the temporary traffic signs are no longer visible on the motorway. For this phase, for the night of 8-9 February, as for the pre-closure phase, no distinction was made in the data for the hour when the road was reopened at 04:18. As a result, for the period 04:00 - 05:00 it is still visible that vehicles are turning around because of the closed Schipholweg, Figure 40. For the night of 6-7 February, it is more clearly visible that it is decreasing due to the reopening of the road. For this night, the road is opened at 03:05, which means that for a large part of the hour, the road is available for traffic. As a result, the percentage of vehicles making a turn back to the motorway decreases. In addition, the motorway traffic volume results show that the number of vehicles on the on- and off-ramps increases again during the post-closure phase.

6 Case study A27 exit Hagestein

The behaviour of road users around closures is analysed using a case study of the area around the A27 Hagestein exit towards Utrecht. Drivers' route choices during the closure of a road in the local road network after the motorway exit will be determined using observations from ANPR cameras. Static traffic signs will be placed along the motorway to announce the closure and the corresponding detour. NDW detection loops are used then to determine traffic volumes on the motorway and the average speed per hour in order to analyse behaviour around the announcement and detour signs. This chapter begins by introducing the case study and the measurements performed.

The analysis for the A27 case study involves similar methods to those used for the A9 case study. The approach for the A27 case study is illustrated in Figure 19. This chapter begins with an in-depth examination of the route choices observations, which is more extensive than in the A9 case study. It examines multiple routes around the closure, including shortcuts and detours, providing a more comprehensive understanding of the route choices made by road users. To identify these routes, the analysis follows the same steps as the A9 case study. Firstly, average traffic volumes are determined and compared with those observed on closure days and during ANPR camera measurements. This includes four Tuesday nights from 27 February 2024 to 19 March 2024. A linear regression is then used to estimate the expected number of vehicles diverted from their usual route, which allows to determine the route decisions of the vehicles. The motorway observation analysis follows similar steps to the A9 case study. This includes comparative assessments of traffic volume and speed on the motorway, similar to establishing baselines and identifying deviations on days with and without road closures.

6.1 Scope A27 exit Hagestein

During the period from 27 February 2024 to 19 March 2024, measurements were taken every Tuesday for the evening and night hours from 21:00 to 04:00. These measurements were done in the surroundings of A27 Exit 27 Hagestein to determine route choices by vehicles during the closure of the Hagenweg.

The Hagenweg is closed on the nights of 27 and 28 February, and 12 and 13 March. The Hagenweg is located at the bottom of exit 27 Hagestein in the direction of Vianen (the first exit on the roundabout after the exit). Due to the closure, it is not possible to enter Vianen via this road, an alternative route must be taken. To avoid traffic disruption, static traffic signs have been placed on the A27 in the direction of Utrecht to inform drivers of the closure and to indicate the corresponding detour. The associated detour involves that traffic must continue towards Vianen via the next exit (Exit 28 Nieuwegein) to return to Exit 27 Hagestein but in the direction of the Everdingen interchange. However, it is possible to take the Hagestein exit and continue via a shortcut. The shortcut is to choose the second exit at the bottom of the Hagestein roundabout and head towards Vianen via the Lange Dreef.

On the night of 5 March to 6 March 2024, a baseline measurement was made of traffic on exit Hagestein, exit Nieuwegein, access Nieuwegein and Lange Dreef with ANPR cameras. Additionally, a baseline measurement was carried out on the night of 19-20 March 2024 for traffic on exit Hagestein, exit Nieuwegein, and access Nieuwegein and Hagenweg with ANPR cameras. These baseline measurements are used to determine whether any unusual traffic patterns were observed on the nights of the closure and to estimate how many vehicles are expected at the various locations.

6.2 Route Choice Observations

ANPR cameras were used to track the chosen route of the traffic. These were placed at various locations around the closure and detour. The ANPR cameras record the number of vehicles per hour that have passed the camera location. In addition, the records of the cameras are matched together allowing a vehicle that has been recorded by multiple cameras over a period of time to be identified. This makes it possible to determine the route taken by the vehicles that intended to use the Hagenweg.

The ANPR camera locations are shown in Figure 41. Different routes can be found based on the ANPR cameras implemented. A route is defined when a vehicle is detected by two or more cameras. Based on the traffic situation, three route scenarios have been defined that are potentially found by the ANPR cameras. The first route scenario is a vehicle using the specified detour, which means the vehicle is detected twice. First, the vehicle is detected at the exit of Nieuwegein and then by the camera at the location of Access Nieuwegein. This route shows that the vehicle has turned to enter Vianen in the opposite direction of the Hagestein exit (green route). A second route scenario is indicated by a vehicle that has taken the shortcut. This route is found when a vehicle is recorded by the camera at the Hagestein exit and at Lange Dreef (orange route). Finally, in the third route scenario, a vehicle is recorded three times. This is the case when a vehicle takes the Hagestein exit and then cannot continue towards Vianen due to a closure on the Hagenweg. If the vehicle is then detected at the Nieuwegein access and exit, this indicates that the driver turned at the roundabout at the end of the Hagestein exit to use the detour (blue route).

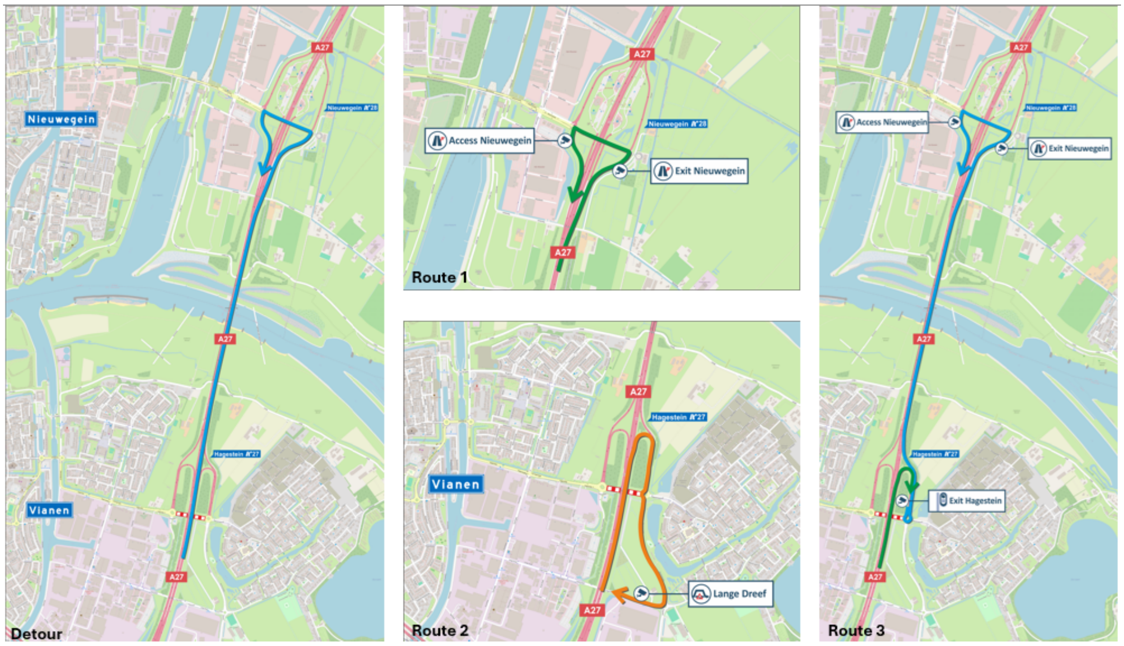

Figure 41: ANPR camera locations and associated routes case study A27

6.2.1 General traffic volumes

The number of vehicles per hour was measured at five different locations on four different nights. To estimate how traffic flows change when a closure is in place, the baseline measurements from 5-6 March and 19-20 March were used to determine what traffic volumes are under normal conditions. These traffic volumes are determined for the ANPR camera locations and any route detections and are shown in Figure 42. The corresponding routes are shown in Figure 41. On the secondary road network of the A27 (the A27 motorway is the primary road network), the number of vehicles on the Hagenweg and Lange Dreef was measured once each on different days. This is due to the availability of the cameras. On the last day of the measurements, the camera was switched from Lange Dreef to Hagenweg. This means that there are not two baseline measurements for these locations. The results show that on 19 March vehicles were detected using the exit Nieuwegein - access Nieuwegein. This route can be used to turn around if vehicles have gone the wrong way. In addition, there are a number of fast-food restaurants around the exit. However, the detection interval used is too small to detect these vehicles as a combination if they pass by one of these restaurants.

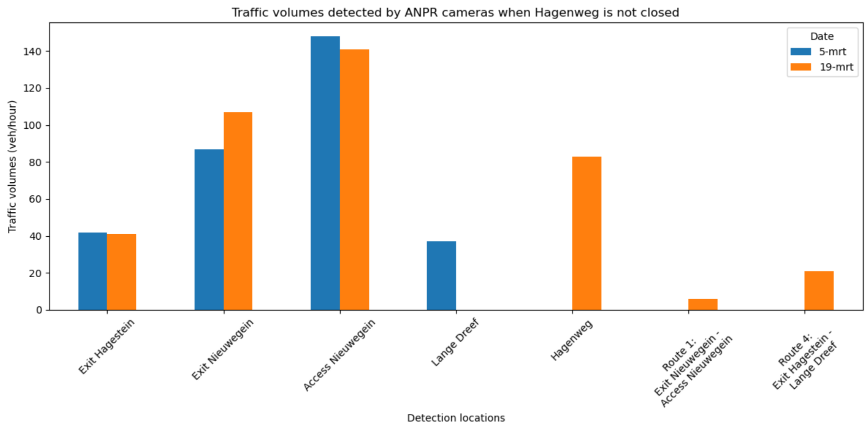

Figure 42: Traffic volumes detected by ANPR cameras in normal conditions between 21:00 and 22:00

6.2.2 Changes in traffic volumes

Pre-closure Hagenweg: The pre-closure phase is the period when there are signs along the motorway but the closure has not yet started. This phase is actually formed by two periods. The period in which the signs are installed. In other words, when the signs become visible to road users. During this period, not all traffic signs may be visible yet. Then, when all the signs are visible, it is actually the start of the second period. For the Hagenweg case study, this period was between 20:00 and 21:00 on 27 February and 12 March. However, it is not known when all the traffic signs were visible, so the whole period is analysed as a complete block rather than divided into two different sub-phases.

During the hour before the closure, it is not visible on the motorway whether the Hagenweg is closed or not. As a result, vehicles following the traffic signs will take the Nieuwegein exit and the Nieuwegein access ramp in the direction of Vianen. However, if the driver chooses to take the exit anyway, the driver will not encounter any obstacles and can continue his journey via the Hagenweg. Based on the camera detections of the vehicles observed by more than one camera, it can be seen that a number of vehicles use the Nieuwegein exit and the Nieuwegein ramp on each measurement day. As this was observed on all four days, it is not possible to conclude from these results alone whether the driver was following the detour or not. As the Hagenweg had not yet been closed, it can be assumed that the vehicle detected by the camera at the Hagestein and Lange Dreef exit would have taken this route under normal conditions.

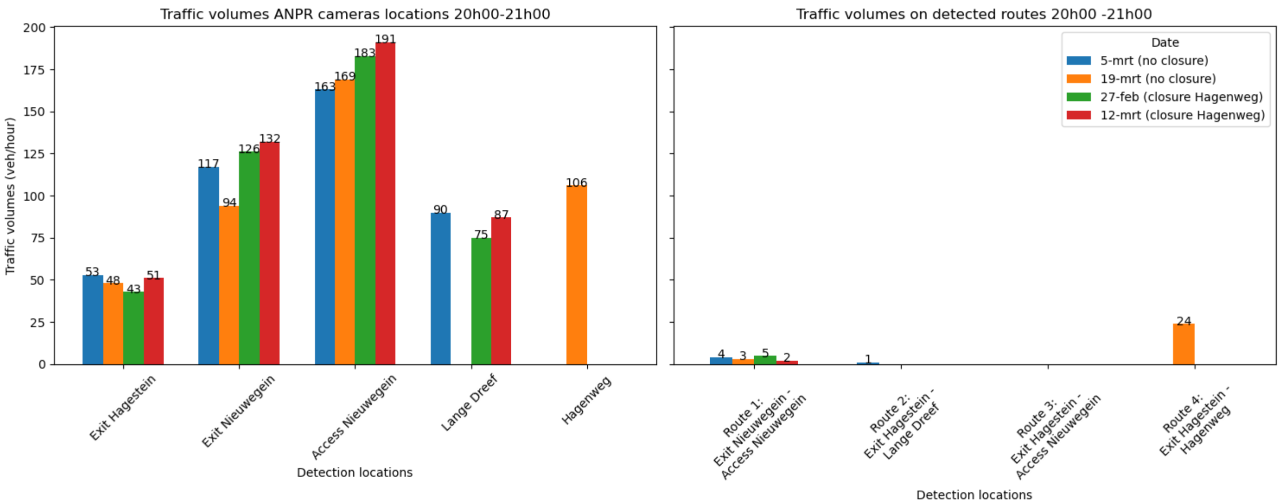

Figure 43: Traffic volumes detected by ANPR cameras between 20:00 and 21:00.
Detected route: vehicles detected at multiple ANPR cameras.

Closure phase Hagenweg: The closure phase will take place between 21:00 and 04:00 on 27 February and 12 March. Traffic routes and changes in traffic volumes have been analysed on an hourly basis. First, the period between 21:00 and 22:00 will be discussed. Then the same steps are applied to the hours between 22:00 and 04:00. The results of these time periods are shown in Appendix K.1.

Traffic patterns in the area around the Hagenweg changed as a result of the closure. The baseline measurements were compared with the closure days to assess the changes that occurred between observations. The measurements of the ANPR cameras are shown in Figure 44.

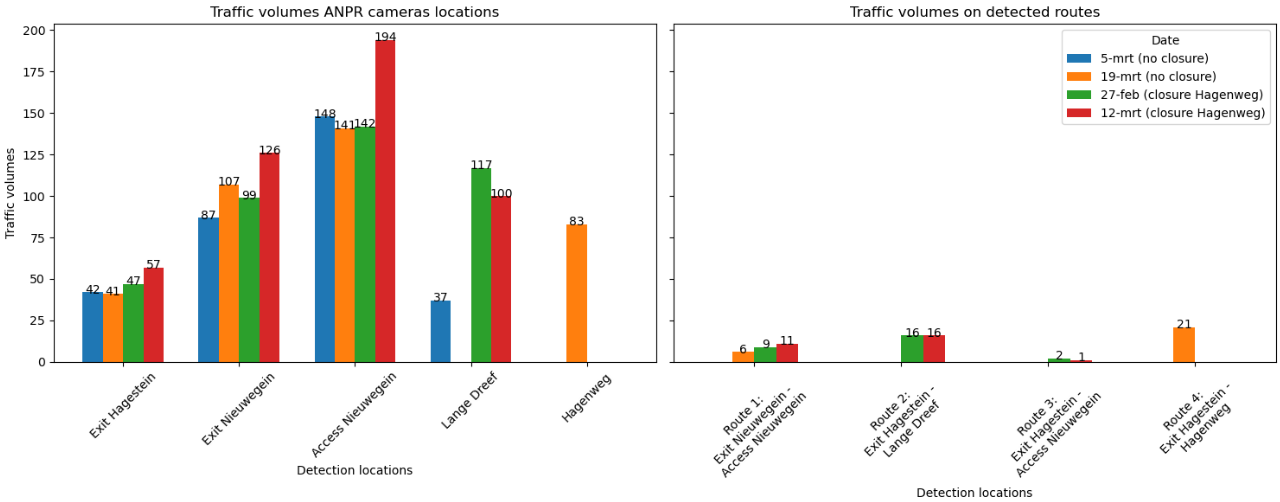

Figure 44: Traffic volumes detected by ANPR cameras between 21:00 and 22:00
Detected route: vehicles detected at multiple ANPR cameras.

There is a distinction between the measurements on March 12 and the other days. More vehicles were counted at all exits on March 12 between 21:00 and 22:00. It is additionally important to note that on the days when the road is closed, there are more vehicles detected on Lange Dreef. It can therefore be seen that on these days vehicles take the route from the Hagestein exit to the long lane, which is not visible on days when there is no closure. In addition, the measurement on 19 March shows that a large part of the number of vehicles on the Hagenweg do not come from the Hagestein exit. In these cases, the vehicles coming from other locations, such as Hoef en Haag, cannot use the Hagenweg as well and therefore also use the route via Lange Dreef in the direction of Vianen. Although the numbers are not exactly the same because the days are different, the results support this finding. On 19 March, there are 62 vehicles (Hagenweg - Route 4) coming from places other than the Hagestein exit. On the days when the road was closed, 16 vehicles were seen using Route 2. Including the 62 vehicles from other locations, this gives a rough estimate of 78 additional vehicles using the Lange Dreef. On 5 March, 37 vehicles were seen using the Lange Dreef. Combined with the additional vehicles, this gives an estimate of 115 vehicles using Lange Dreef on the days of the closure. This estimate is comparable to the values for 27 February and 12 March (117 and 100 respectively).

From the routes identified, it can be seen that different routes are seen during a closure compared to those that are seen less or not at all during normal conditions. Routes 2 and 3 are not observed under normal conditions and the number of vehicles on route 1 is higher than during normal conditions. In Figure 44 it can be seen that there is a difference in the number of vehicles seen first at the Hagestein exit and then at the Nieuwegein exit compared to the number of vehicles first seen at the Hagestein exit and then at the Nieuwegein exit. In some cases, the number of vehicles reaching the Nieuwegein access ramp within 10 minutes is lower. One of the reasons for this could be that the vehicles passed one of the fast food restaurants and therefore did not meet the time frame. Or the vehicles may have taken the wrong exit by mistake and their final destination was not Vianen but Nieuwegein. The reason for the difference in the measurements cannot be identified from the results. For this reason, it was decided to disregard vehicles not seen within 10 minutes on the Nieuwegein access ramp due to the closure of the Hagenweg when determining the routes taken to Vianen.

Post-closure phase Hagenweg: Similar to the pre-closure phase, there is also a time when the closure has ended but the road signs have not been completely removed. This is the post-closure phase. This phase took place between 04:00 and 05:00 on both closing nights. During the hour, the Hagenweg will be reopened. The hour will therefore consist of a phase in which the detour must still be followed and a phase in which traffic will be able to drive to Vianen via the Hagenweg without any problems.

In Figure 45 the results of the number of vehicles registered at the ANPR camera locations are presented, as well as the number of vehicles found to have travelled a particular route. On 27 February, two routes were found around the Hagenweg closure, routes 1 and 2. On 12 March only route 2 was observed.

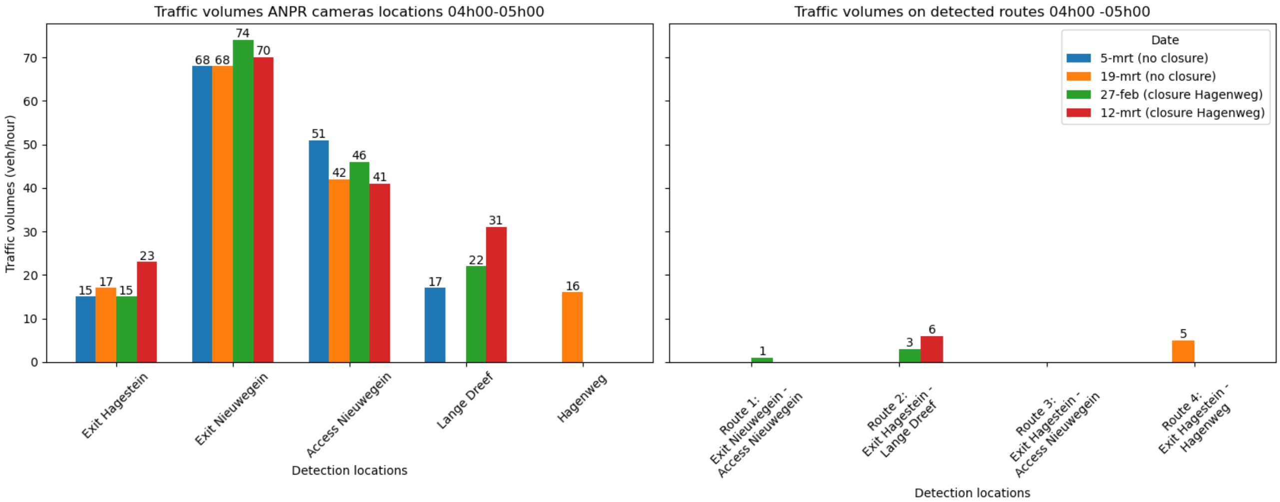

Figure 45: Traffic volumes detected by ANPR cameras between 04:00 and 05:00
Detected route: vehicles detected at multiple ANPR cameras.

6.2.3 Traffic volumes coming from the A27 motorway towards Hagenweg

In order to establish the detour choices made by motorway traffic when a secondary road network is closed, it is important to determine the number of vehicles affected by the situation. In this case study, this refers to the traffic that would normally use Hagenweg when travelling from the A27 motorway. This traffic will then take the Hagestein exit to enter the Hagenweg.

However, when the Hagenweg is closed, traffic has multiple routes and choices to reach its final destination. For example, the road user can select between different routes or decide to avoid the Hagenweg. This makes it a difficult situation to determine the number of vehicles using a single measurement. On 19 March, a baseline measurement of the number of vehicles was performed. This measurement gives an indication of the number of vehicles, but this single measurement does not give a complete insight into the number of vehicles at the day of closure, as it can vary from day to day and from hour to hour. For this reason, in order to predict the number of vehicles on the Hagenweg on the day of the closure, the linear regression method described in subsubsection 2.4.3 was applied. This linear regression method uses the difference between the number of vehicles at the Hagestein exit and the Nieuwegein exit on 19 March and on the day of the closure. In addition, the numbers on the Hagenweg on 19 March were used as a basis for the expected number of vehicles. The corresponding linear regression plots are shown in subsection I.2.

Pre-closure phase: The linear regression method is applied for the pre-closure phase between 20:00 and 21:00. This resulted in that there are 22 vehicles expected on 27 February and 25 vehicles on 12 March.

Closure phase: Similarly to the pre-closure phase, the linear regression method was conducted for the closure phase. The method resulted in that on Tuesday 27 February between 21:00 and 22:00, 22 vehicles are expected to use the Hagenweg from the motorway in a normal situation, and on Tuesday 12 March the expected value is 27 vehicles.

The routes found by the ANPR cameras can be used to determine how many vehicles actually drove the expected routes. These values are based on the number of vehicles following Route 1 and Route 2. Route 3 is not included because it is already included in the counts for Route 1, as Route 3 also passes the Nieuwegein exit and the Nieuwegein access camera, but is recorded an extra time by the Hagestein exit camera. Including Route 3 would result in double counts. The results are shown in Table 31. The number of vehicles on different routes between 21:00 and 22:00 on 27 February is higher than expected, but the number of vehicles on 12 March is the same as expected. This method cannot be used to determine the actual number of vehicles between 20:00 and 21:00. This is because there are no measurements of vehicles on the Hagenweg.

Table 31: Number of vehicles affected by closure Hagenweg

Traffic volumes 21h00 - 22h00		
Date	**27 February**	**12 March**
Expected traffic Hagenweg	22	27
Route 1	9	11
Route 2	16	16
Route 3	2	1
Total Routes*	27	28
Total number of vehicles**	25	27

* Total route = Total number of vehicles detected on routes .
**Total number of vehicles = total different vehicles detected on routes

The same steps are applied for the other hours in the closure phase. The results of these time periods are shown in Table 32.

Table 32: Expected traffic Hagenweg and measured vehicles on routes 22h00-04h00

Time	**Date**	**Expected traffic Hagenweg**	**Total Routes***	**Total number vehicles****	**Route 1**	**Route 2**	**Route 3**	**Avoiding Hagenweg**
22-23	27-feb	18	22	22	9	12	1	
	12-mrt	27	29	29	7	21	1	
23-24	27-feb	15	14	12	3	9	0	
	12-mrt	16	9	9	2	7	0	
00 01	28-feb	4	8	8	3	5	0	
	13-mrt	6	16	16	8	7	1	
01 02	28-feb	1	2	2	1	1	0	
	13-mrt	4	8	8	2	5	1	
02 03	28-feb	0	1	1	1	0	0	
	13-mrt	0	2	2	1	1	0	
03 04	28-feb	4	7	7	2	4	1	
	13-mrt	3	3	3	1	2	0	

* Total route = Total number of vehicles detected on routes .
**Total number of vehicles = total different vehicles detected on routes

Post-closure phase: On 28 February and 13 March, the Hagenweg will be open to traffic from 04:40. As there are no cameras installed on the Hagenweg on these nights, it is not possible to get a complete overview of the number of vehicles using the Hagenweg from the motorway in the direction of Vianen during this hour. Therefore, the predicted number of vehicles from the linear regression method was used. These values are based on the number of vehicles recorded on the Hagenweg on 19 March and the difference between the number of vehicles at the Hagestein exit and the Nieuwegein exit on the days of the closure. The linear regression resulted in 8 expected vehicles on 28 February and 11 vehicles on 13 March, Table 33.

Table 33: Expected number of vehicles Post-closure

Expected vehicles Post-closure		
Timeframe	04h00 - 05h00	
Date	27 February	12 March
Expected traffic Hagenweg	8	11
Route 1	1	0
Route 2	3	6
Route 3	0	0
Total Route	4	6
Total number of vehicles	4	6

* Total route = Total number of vehicles detected on routes .
**Total number of vehicles = total different vehicles detected on routes

6.2.4 Route selection analysis

Pre-closure phase: For the pre-closure phase, only the number of vehicles expected to use the Hagenweg during the hour and the number of vehicles seen at the Nieuwegein exit and Oprit Nieuwegein are known. The other routes were not observed, Figure 43. Based on this data, a rough estimate can be made of the number of vehicles already following the traffic signs during this phase. However, it is not known whether the vehicles reversing via the Nieuwegein exit are actually reversing because of the closure or for some other reason. The results of this analysis are shown in Table 34.

Table 34: Route selection Pre-closure

Route selection Pre-closure		
Timeframe	20h00 - 21h00	
Date	27 February	12 March
Expected traffic Hagenweg	22	25
Route 1	5	2
Route 2	0	0
Route 3	0	0
Percentage route 1	22.7%	8%

Closure phase: With the predicted traffic volumes for the closure of Hagenweg and the traffic volumes for the alternative roads, the proportion of traffic using the detour and the proportion using the alternative route can be computed.In addition, the number of vehicles that avoid the closed road by adjusting their travel plans, in response to the pre-announcement sign, can be determined. First, the period between 21:00 and 22:00 is considered for the closing phase. Then the other time periods are considered using the same steps.

As it is not possible to determine from the traffic counts carried out how many vehicles chose another route to avoid the Hagenweg, an estimate of the corresponding percentages was made based on the expected traffic volume on the Hagenweg and the recorded number of vehicles on the different routes. The percentages based on expected vehicles can give an indication of whether there are more or fewer vehicles. Fewer vehicles indicate that vehicles have chosen to avoid the Hagenweg. Therefore, the difference between the expected number of vehicles and the actual number of vehicles is equal to the number of vehicles that avoided the Hagenweg. If there are more vehicles, this indicates that it was a busier period than expected, so the percentage of vehicles will be higher than 100% and therefore the route alternatives will also add up to higher than 100%. The number of vehicles avoiding Hagenweg will then be 0%. In addition, the percentages of route choices will also be based on the actual number of vehicles affected by the closure. The reason for this is that these percentages will give an indication of the follow-up behaviour of the announcement and detour routes when they are actually confronted with the closure. The results are shown in Table 35.

Table 35: Route percentages

21h00 - 22h00	**Percentage compared to expected traffic volumes**		**Percentage compared to counted traffic volumes**	
Date	**27 February**	**12 March**	**27 February**	**12 March**
Percentage vehicles	116%	100%	100%	100%
Percentage route 1	33%	37%	28%	37%
Percentage route 2	74%	59%	64%	59%
Percentage route 3	9%	4%	8%	4%
Percentage Avoiding Hagenweg	0%	0%	0%	0%
Percentage follow up on detour	33%	37%	28%	37%
Percentage not following detour	83%	63%	72%	63%

In the results, Route 1 shows the traffic that followed the detours, Route 2 took the detour and vehicles from Route 3 turned back to the detour. For the actual traffic counts it is not possible to determine vehicles avoiding the closed road, therefore its value will be equal to 0%. Finally, in order to get a more detailed overview of the route choices made during the road closure for each situation have been chosen to give the best indication of the situation. The days and times where the measured number of vehicles correspond to the expected number of vehicles, the percentages are based on the total traffic measured at the specific time period. It is assumed that there is no diversion of traffic towards other routes. For the days and periods with less traffic than expected, the percentages are based on the expected number of vehicles having to make a different choice due to the road closure.

As a result, the percentages shown in “Percentage compared to counted traffic” in Table 35 give the best indication of the situation for the period studied from 21:00 to 22:00. The closure of Hagenweg on 27 February 2024 affected 25 vehicles from the A27 motorway between 21:00 and 22:00. A detour is provided on the motorway during this time. From the measurements, it can be concluded that this detour is used by 28% of the vehicles. Similar results are found for the closure of Hagenweg on 12 March 2024. During this time, the number of vehicles taking the detour is slightly higher with 37% of the total number of vehicles affected.

For 21:00 and 22:00, percentages were calculated based on the expected For 21:00 and 22:00, percentages were calculated based on the expected and the number of vehicles found on the different routes to determine the share of each route for the other time periods. Using the values found for the expected number of vehicles, the total number of vehicles measured and the number of vehicles per route for these time periods are shown in Table 32. Comparing the values found at the cameras with the expected values, it can be seen that for 23-24 hours the measured values are lower than the expected value. Therefore, for this period, the difference was calculated as the number of vehicles that avoided the route by staying at home or taking a completely different route. It was also determined which vehicles did or did not follow the detour based on the values found. The final route distribution percentages from the analysis are shown in Table 36.

Table 36: Percentages Routes 22h00-04h00

Time	**Date**	**Route 1**	**Route 2**	**Route 3**	**Avoiding Hagenweg**	**Follow-up Detour**	**Not follow Detour**
22-23	27-feb	40.9	54.6	4.5	0	40.9	59.1
	12-mrt	24.1	72.4	3.5	0	24.1	75.9
23-24	27-feb	20.7	62.3	0	17	20.7	79.3
	12-mrt	12.3	43.2	0	44.5	12.3	87.7
24-01	28-feb	37.5	62.5	0	0	37.5	62.5
	13-mrt	50	43.8	6.2	0	50	50
01-02	28-feb	50	50	0	0	50	50
	13-mrt	25	62.5	12.5	0	25	75
02-03	28-feb	100	0	0	0	100	0
	13-mrt	50	50	0	0	50	50
03-04	28-feb	28.6	57.1	14.3	0	28.6	71.4
	13-mrt	33.3	66.7	0	0	33.3	66.7

Post-closure phase: For the post-closure phase it is also possible to determine the different route percentages. On 27 February, two routes were found around the Hagenweg closure, routes 1 and 2. The linear regression method calculated that 8 vehicles were expected. Together on routes 1 and 2, 4 vehicles are detected. It was assumed that the other 4 vehicles used the Hagenweg road or avoided the route. On 12 March only Route 2 was observed. This involves 6 out of the 11 expected vehicles by the linear regression method. As on the previous measurement day, the remaining 5 vehicles are assumed to have used the reopened Hagenweg or avoided the route. Based on the numbers obtained, it is possible to estimate the distribution of vehicles on the different routes. These results are presented in Table 37.

Table 37: Expected number of vehicles Post-closure

Route selection Post-closure		
Timeframe	04h00 - 05h00	
Date	27 February	12 March
Expected traffic Hagenweg	8	11
Route 1	1	0
Route 2	3	6
Route 3	0	0
Percentage route 1	12.5%	0%
Percentage route 2	37.5%	54.5%

6.2.5 Statistical chi-squared analysis

To assess whether the situation observed during the closure of the Hagenweg is significantly different from the null hypothesis, the chi-square method is used. The null hypothesis tested by statistical analysis is that vehicles follow the detour route during the closure of Hagenweg.

Four decisions are considered in the analysis of detour decisions. Decision 1, follow the detour. Decision 2, taking the shortcut. Decision 3, returning to the detour route and Decision 4, avoiding the Hagenweg by adjusting travel plans. The associated input variables are presented in Table 38.

Table 38: Statistical chi-squared analysis input variables detour decisions A27

	Expected	**Observed**
Route 1	Total observed vehicles or Total expected vehicles	Exit Nieuwegein - Access Nieuwegein
Route 2	0	Exit Hagestein - Lange Dreef
Route 3	0	Exit Hagestein - Access Nieuwegein
Avoiding Hagenweg	0	Expected vehicles - observed vehicles

Due to the null hypothesis, the expected number of vehicles for decisions 2, 3 and 4 is zero. Similar to the statistical analysis of the A9 case study, an expected value causes the chi-square value to go to infinity. The statistical analysis is therefore based on decision 1. Therefore, the total closure phase is considered whether it is statistically significant or not. The closure phase for the case study on the A27 lasted from 21:00 until 04:00.

Table 39: Statistical chi-squared analysis detours A27

	χ^2	
Time period	**27-28 February**	**12-13 March**
21-22	12.96	9.48
22-23	7.68	16.68
23-24	4.26	12.25
24 01	3.12	4
01 02	0.5	4.5
02 03	0	0.5
03 04	3.57	1.33
$\sum\chi^2$	32.10	48.75

6.3 Motorway Observations

In addition to the measurements, information from the detection loops on the A27 motorway has been analysed. The detection loops were used to gain additional insight into the behaviour of vehicles on the motorway when seeing detour signs and announcements. The detection loops provide data including average speed and intensity per hour. The average speed has been used to determine if there is a difference in speed around the exits and information signs during a closure. The intensity was used to investigate whether behaviour on the motorway in response to the closure could be determined based on intensity. It is also being investigated whether intensity detection on the motorway can provide similar results to ANPR camera measurements for route decisions.

Different detection loops were used to analyse the behaviour of vehicles on the motorway around a detour and their response to the relevant traffic signs. The motorway has been divided into different sections to provide a clear distinction in response to road signs with information and traffic choices visible on the motorway. The different sections of the motorway are shown in Figure 46, and the related information is given in Table 40. The table lists the hypotheses identified during the brainstorming session, Appendix C. Detailed information about the different traffic signs, and locations of the signs of the detour can be found in Appendix J.

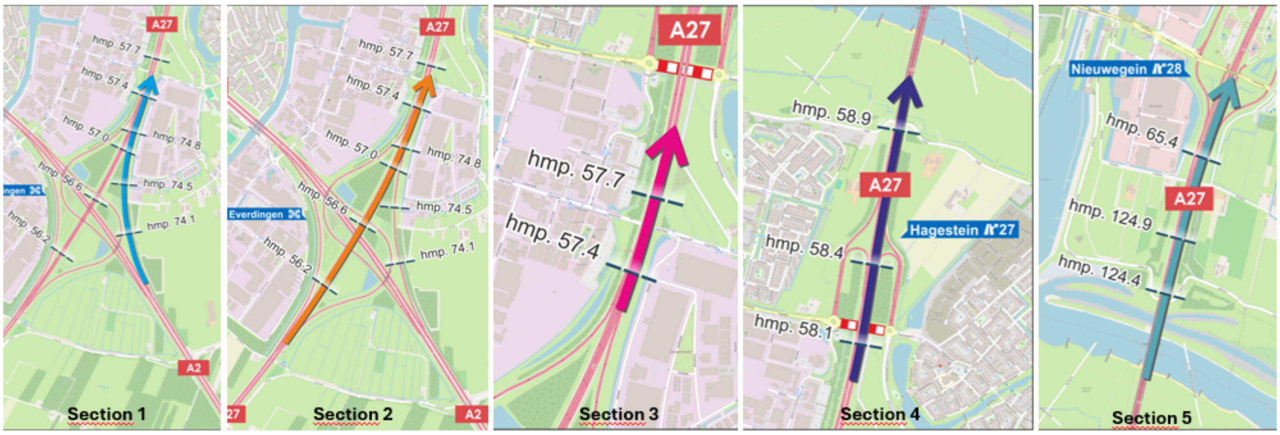

Figure 46: Different motorway sections A27 including detection loops
–: Detection loop

Table 40: Motorway section information

Motorway section	Detection loops	Section Information	Traffic signs	Hypothesis driving bahaviour
Section 1	HMP 74.1 HMP 74.5 HMP 74.8	Announcement Road closure and detour	Yes	Speed remains unchanged Intensity remains the same
Section 2	HMP 56.2 HMP 56.6 HMP 57.0	Announcement Road closure and detour	Yes	Speed remains unchanged Intensity remains the same
Section 3	HMP 57.4 HMP 57.7	Detour specification Start detour	Yes	Speed remains unchanged Intensity remains unchanged
Section 4	HMP 58.1 HMP 58.4 HMP 58.9	Exit Hagestein (HMP 58.1 - 58.4) Access Hagestein (HMP 58.4 - 58.9)	No	Decrease in speed Less intensity difference between HMP 58.1-58.4
Section 5	HMP 124.4 HMP 124.9 HMP 65.4	Detour information Exit Nieuwegein (HMP 124.9 - 65.4)	Yes	Decrease in speed Higher intensity difference between HMP 124.4 - 124.9
Motorway including bend	Without: HMP 56.2 HMP 56.6 HMP 57.0	Motorway including section 1, without section 2	Yes	Speed remains unchanged Less intensity difference around exit Hagestein, higher intensity difference exit Nieuwegein
Motorway including straight	Without: HMP 74.1 HMP 74.5 HMP 74.8	Motorway including section 2, without section 1	Yes	Speed remains unchanged Less intensity difference around exit Hagestein, higher intensity difference exit Nieuwegein

6.3.1 Motorway traffic volumes over the years

In order to determine whether the measured traffic volumes on the motorway on the measurement days are comparable to the expected value, the average traffic volumes for the different detection loops were determined for the period January to March in the years 2022, 2023 and 2024. The results are shown in Figure 47 for the time period 21:00 - 22:00. The other time periods are shown in Table 68 in Appendix K.

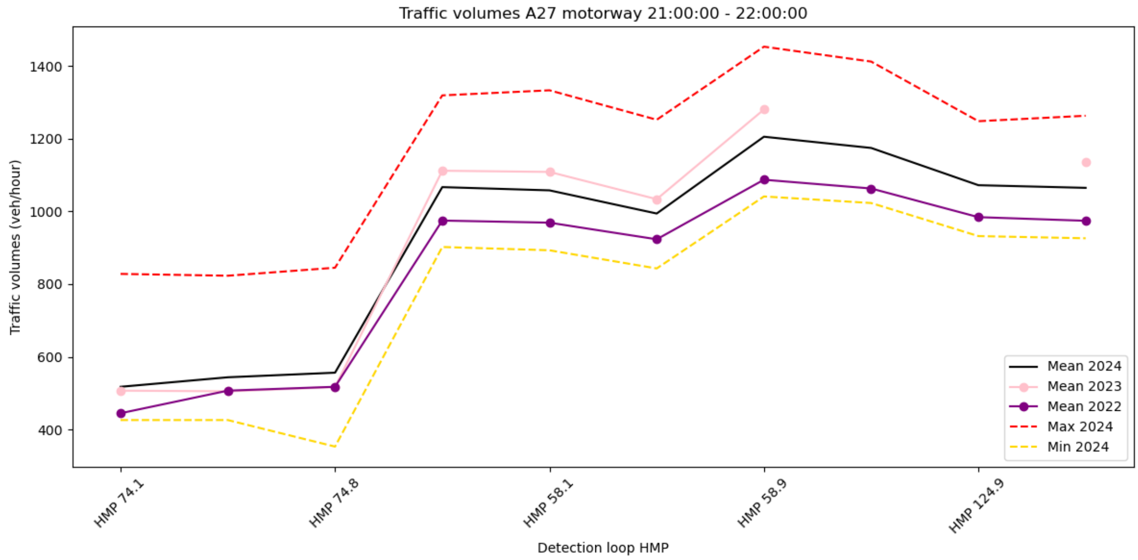

Figure 47: Mean traffic volumes over the motorway section of the A27 in 2022, 2023, 2024.

The average value found shows that the average is slightly lower than the traffic volumes found in 2023, but the average traffic volumes have increased compared to 2022. In addition, the minimum and maximum volumes for the period January to March 2024 are given to determine whether the intensity found on the measurement days reflects a particular case. The traffic volumes found for the measurement days will be compared with the average values found in 2024.

6.3.2 Motorway observations traffic volumes

In addition to the camera measurements of traffic volumes on various roads associated with the detour and closure, the detection loops enable traffic volumes on the motorway to be assessed to determine the impact of the closure on motorway traffic. Motorway traffic volumes can be used to determine whether more or less than average traffic can be expected on the roads around the closure, or whether there are external reasons for different traffic flows on the measurement days.

For the analysis of the traffic volumes on the motorway and at the Hagestein and Nieuwegein exits, the traffic volumes on the entire motorway section on the measurement days were compared with the average traffic volumes in January to March 2022, 2023 and 2024. In addition, the traffic volumes at the Hagestein and Nieuwegein exits have been examined. For the different measurement days (27 February, 5 March, 12 March, and 19 March 2024), the traffic volumes were determined for the entire using the detection loops on the motorway. In 2024, there were no speed measurements on the HMP 56.6 and HMP 57.4 detection loops. Furthermore, on 19 March 2024 between 20:00 and 21:00, no speed measurements are available for all detection loops. After 22:00, measurement data are available again. Missing values are excluded from the analysis.

Pre-closure phase: The pre-closure phase took place between 20:00 and 21:00. In Figure 48 and Figure 49 the traffic volumes over the entire motorway section are shown. The results show contrasting results in the number of vehicles for the 5th and 12th of March for sections 1 and 2. On the 5th of March, section 1 corresponds to the maximum traffic volume found for Tuesdays in the year 2024, whereas in section 2 the number of vehicles corresponds to the minimum value. The same trend, only in reverse, is observed on 12 March. After merging the two sections (from section 3 onwards), the value found on 27 February corresponds to the maximum value for Tuesdays in 2024, and the traffic volume on 5 March corresponds to the minimum value.

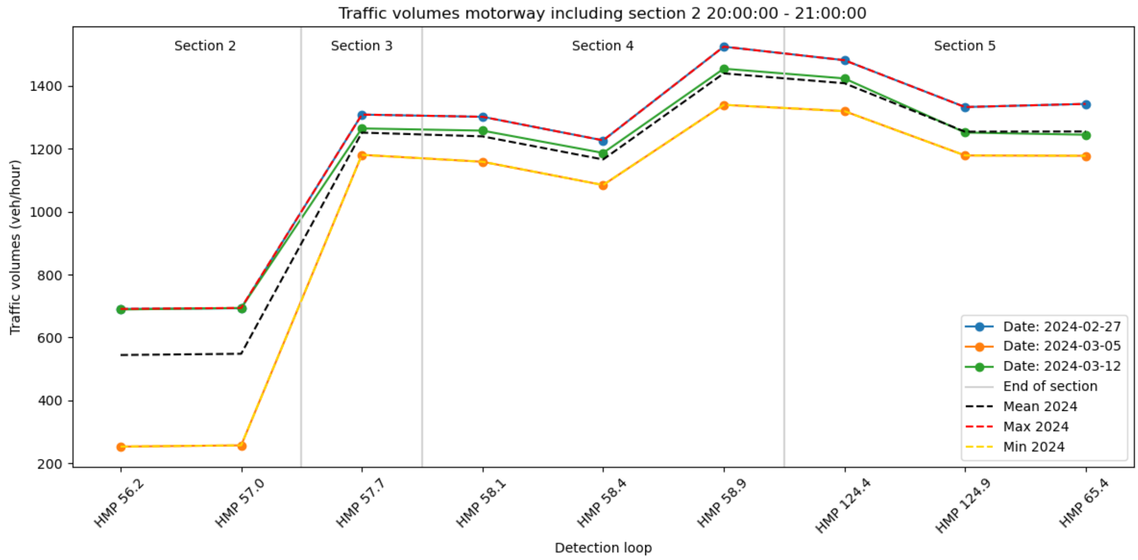

Figure 48: Measurement days traffic volumes motorway including straight A27 Pre-Closure phase.

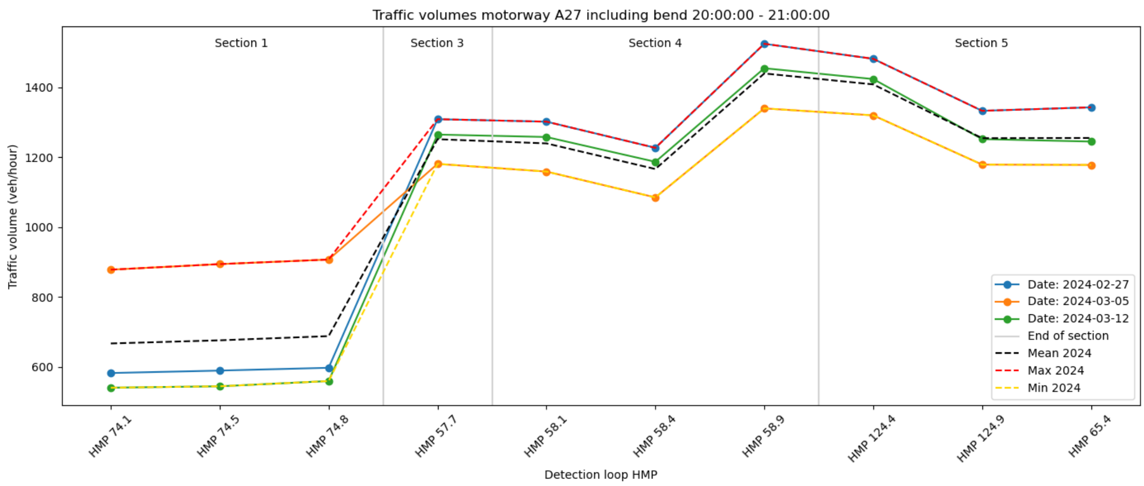

Figure 49: Measurement days traffic volumes motorway A27 including bend Pre-Closure phase.

Closure phase: The same steps as for the pre-closure analysis were carried out for the closure phase. The closure period is from 21:00 to 04:00.

In Figure 50 the traffic volumes observed on the measurement days are shown between 21:00 - 22:00. The traffic volume results show that an irregular flow of vehicles can be observed on 5 and 12 March 2024. On 5 March, a higher than average traffic flow is observed in section 1, but when the traffic flows of sections 1 and 2 are combined after the junction, the total traffic flow is slightly lower than average. This is explained by the fact that the measured traffic volumes in section 2 are much lower than average, as shown in Figure 51. However, this does not show a major difference to the traffic flow on the rest of the motorway and therefore around the Hagestein and Nieuwegein exit, as the traffic flow is slightly lower, but does not show extreme differences further on. The difference in traffic flow between sections 1 and 2 therefore appears to be a result of a prior disruption in the road network. On 12 March, sections 2 to 5 show that many more vehicles are observed compared to the average case. In section 1 no higher volumes were observed. The higher traffic volume after the junction (section 3) is therefore a result of the higher number of vehicles coming from the A27 (section 2). To assess whether the higher volume of vehicles also affects the number of vehicles using the Hagestein and Nieuwegein exits, the differences between the HMP 58.1 and HMP 58.4 and HMP 124.4 and HMP 124.9 detection loops are compared.

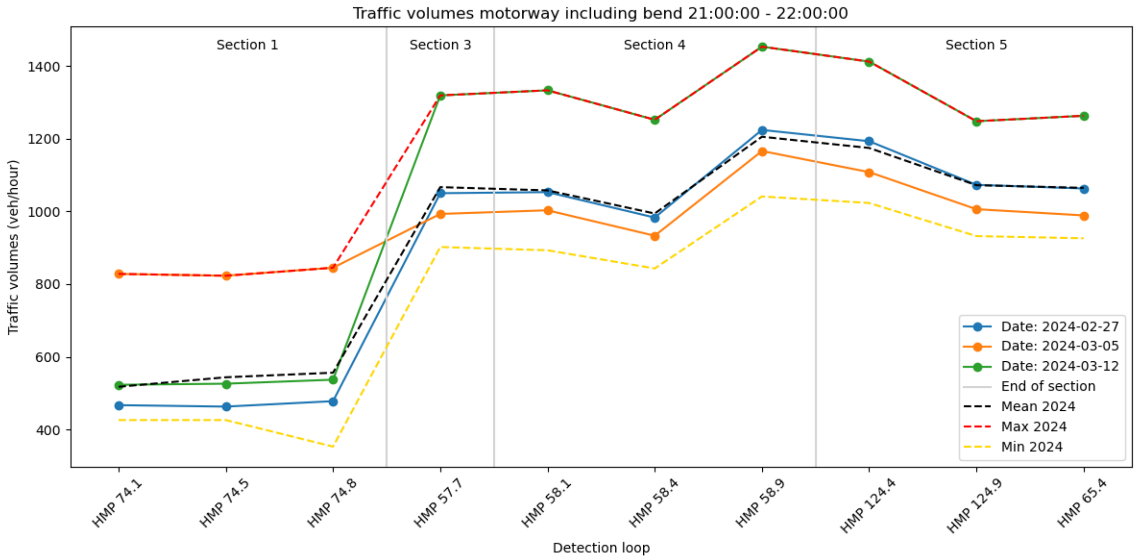

Figure 50: Measurement days traffic volumes motorway A27.

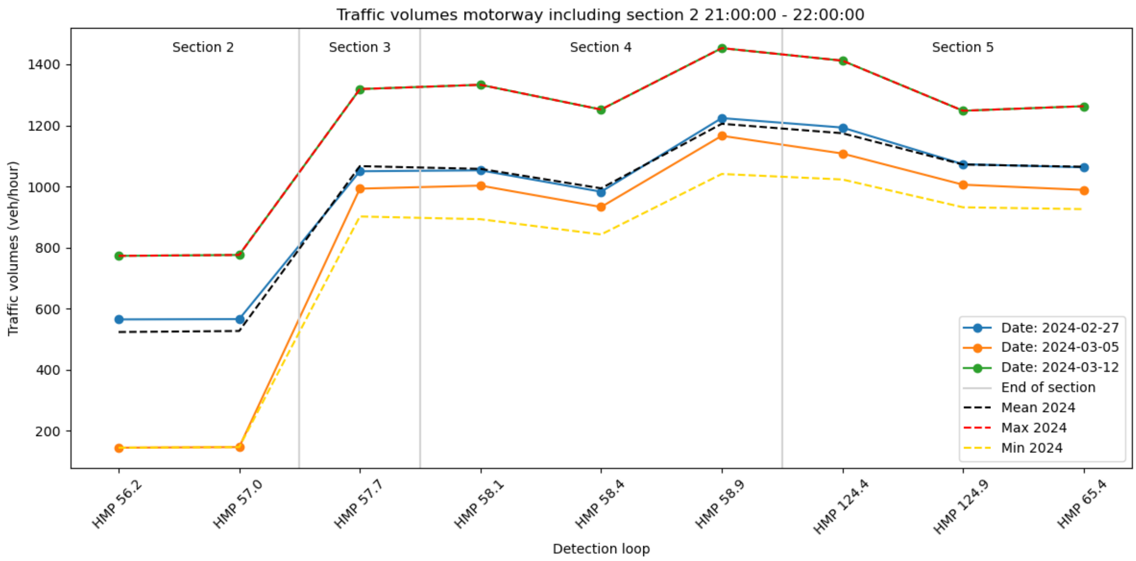

Figure 51: Measurement days traffic volumes motorway A27 (section 2).

The other time periods within the closure phase are analysed as well. On 19 March 2024, there were no measurements from the detection loops until 2200, so no average speed or traffic volume is known. From 2200, detection loops started operating but there is no information on whether this was at the beginning of the hour or later. For this reason, values for traffic volumes and speed have been taken from 2300 onwards.

In the time period 21:00 -22:00, it was found that on the 12th of March the traffic volume was highest on Tuesdays from January to March. On the night of 12-13 March, the same was found for 22:00 - 23:00 and from 03:00 onwards. The Figure 52 shows the traffic between 23:00 and 24:00. On the 19th of March, no particular number of vehicles was found on the motorway. The values found are around the calculated average. For the remaining periods and section 1, which are shown in Table 69 in Appendix K, no trends other than those already described were observed.

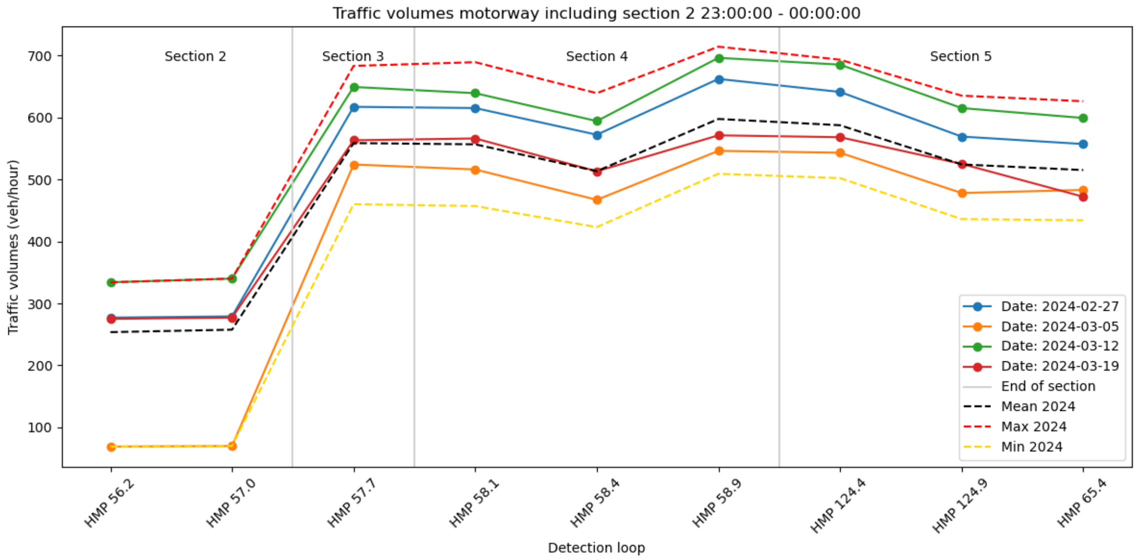

Figure 52: Traffic volumes 23-24

Exit Hagestein and Exit Nieuwegein
Detection loop HMP 58.1 is located shortly before the Hagestein exit and detection loop HMP 58.4 is located after the exit. This means that the difference in intensity measured between the loops reflects the number of vehicles using the exit. The number of vehicles using the Nieuwegein exit can be determined from the difference between loops HMP 124.4 and HMP 124.9. The average, minimum and maximum number of vehicles was determined for the both exit Hagestein and exit Nieuwegein. These results were compared with the values obtained on the days of measurement. In order to determine the impact of the closure using the NDW data, the following will be considered:

The closure of the Hagenweg is expected to result in more vehicles using the Nieuwegein exit and fewer using the Hagestein exit. The difference will be corresponding to the number of vehicles expected to use the Hagenweg.

The results are shown in Figure 53 and Figure 54 for the time period 21:00 - 22:00. The results for Exit Hagestein show that on the measurement days, the volume on the exit ramp is higher than the average between 21:00 and 22:00 for each day. It was also observed that the maximum measured value corresponds to the number of vehicles recorded on Tuesday 12 March for both exits. The same trend is observed for the traffic volume on the motorway, where this date also corresponds to the highest traffic volume over the entire motorway section. In addition, it can be seen that on the day of the other closure, more vehicles are detected than average, but on the day without the closure, fewer vehicles are detected seen at Exit Nieuwegein. This indicates that more vehicles use the Nieuwegein exit due to the closure and the corresponding detour.

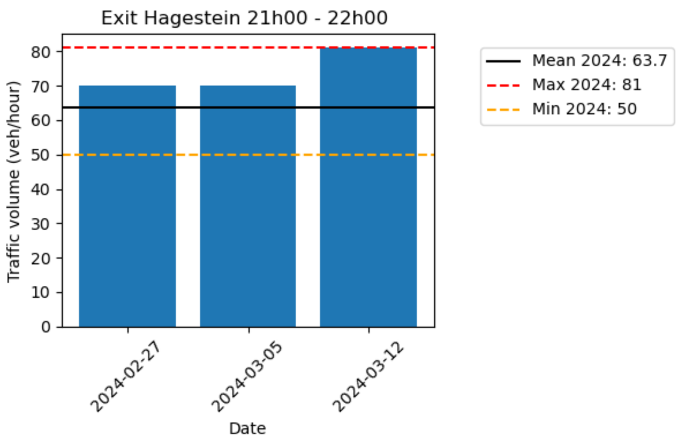

Figure 53: Traffic volumes exit Hagestein.

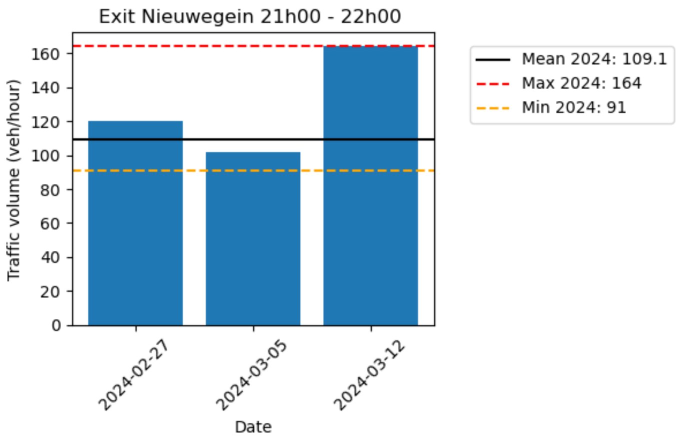

Figure 54: Traffic volumes exit Nieuwegein.

The results of the other time periods are shown in Table 41. The results show no clear difference in the use of the exit on the days when Hagenweg is closed. The values are higher than average on both days and therefore, using only the motorway data, no difference can be seen at the closure at the secondonary network of the motorway. However, the results show that more vehicles were counted on the Nieuwegein exit ramp until midnight than on the other two days. Nevertheless, it must be taken into account that there was a higher volume of traffic on the motorway during these hours, which could be the reason for the higher number of vehicles on the exit ramp. Therefore, counting the number of vehicles at the exits using NDW data does not give a clear indication of whether there is an impact of a closure in this case.

Table 41: Number of vehicles on exit Hagestein and Nieuwegein

		Exit Nieuwegein				**Exit Hagestein**			
Time	**Date**	**Vehicles**	**Mean**	**Min**	**Max**	**Vehicles**	**Mean**	**Min**	**Max**
22-23	27-feb	110	101	91	129	49	50.9	32	68
	5-mrt	92				61			
	12-mrt	129				68			
	19-mrt	-				51			
23-24	27-feb	72	63.4	43	80	43	43.3	31	53
	5-mrt	65				49			
	12-mrt	70				45			
	19-mrt	43				53			
00 01	28-feb	36	36.8	25	44	13	22.2	13	29
	6-mrt	36				25			
	13-mrt	42				22			
	20-mrt	37				18			
01 02	28-feb	28	27.4	18	40	6	9.4	5	12
	6-mrt	27				12			
	13-mrt	36				12			
	20-mrt	30				9			
02 03	28-feb	19	20.3	13	28	5	8	3	12
	6-mrt	23				9			
	13-mrt	18				6			
	20-mrt	17				12			
03 04	28-feb	36	31.8	37	40	14	15.9	7	22
	6-mrt	35				22			
	13-mrt	31				9			
	20-mrt	27				16			

Post-closure phase: Figure 55 shows the traffic volumes for the different sections of the motorway between 04:00 and 05:00. The closure days show a traffic volume around the 2024 average from section 3 onwards, which means that the number of vehicles is expected to be the same as the normal situation without the closure.

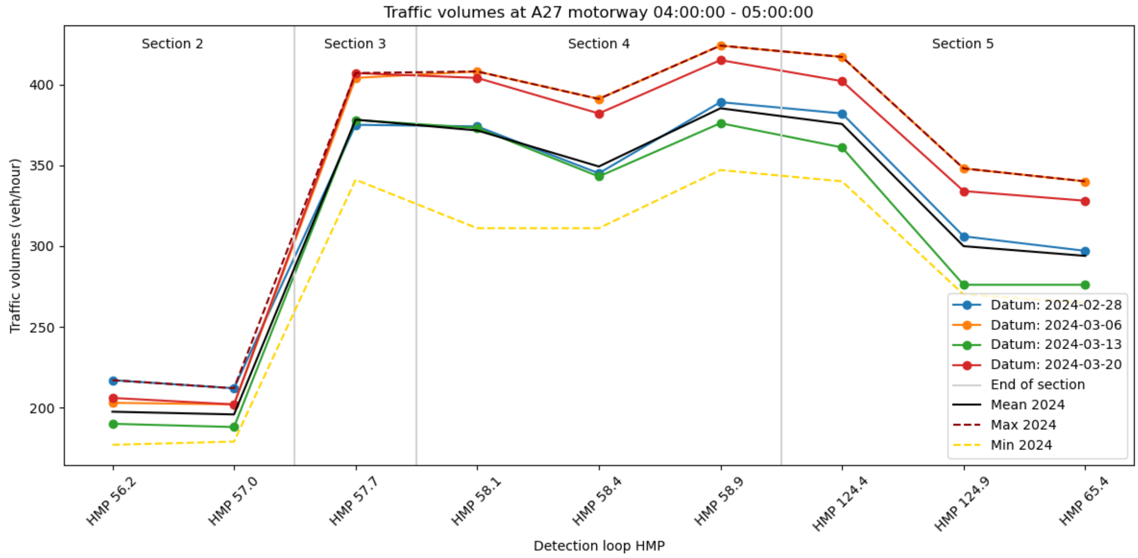

Figure 55: Traffic volumes A27 including section 1 post-closure phase

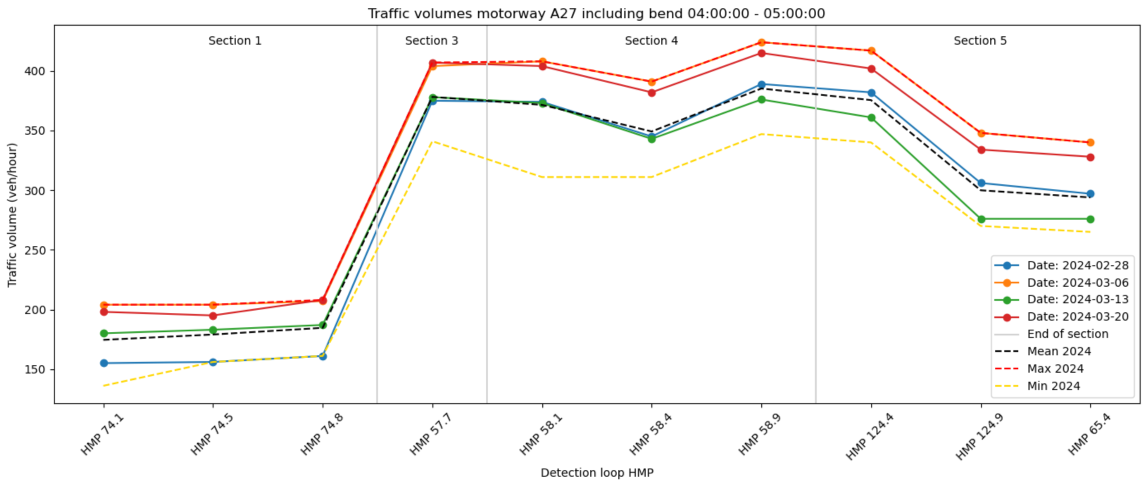

Figure 56: Traffic volumes A27 including section 2 post-closure phase

6.3.3 Motorway average speed over the years

In order to estimate whether traffic changes its speed when it is informed of closure and detour, it is required to estimate the speed normally driven on the motorway sections. This is done by taking the average for the period January to March for the years 2022, 2023 and 2024 and then comparing these values. The results are shown in Figure 57 for the time period 21:00 - 22:00. The other time periods are given in Table 70 in Appendix K. In addition, the maximum and minimum values obtained for 2024 were determined. This range between the maximum and minimum value of the speed gives an indication of whether the values for the different measurement days are a deviation from the normal situation. The results show that there are minor differences in the average speed for the different years. Therefore, to compare the measurement days, the values are compared with the average value found in 2024.

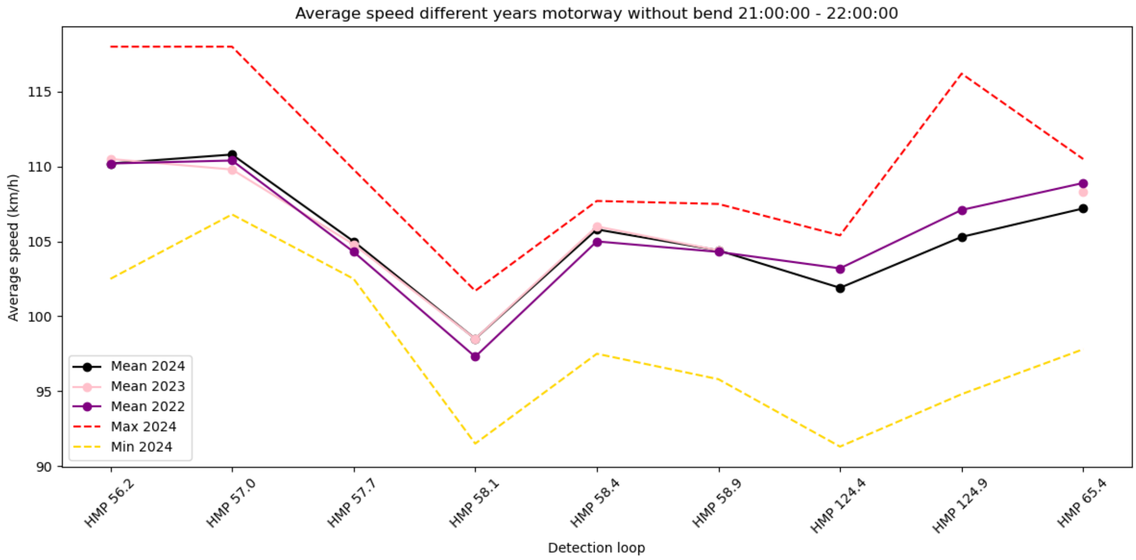

Figure 57: Average speed over the years over the entire motorway section.

6.3.4 Motorway observations average speed

The average speed per hour on the road is used to compare the behaviour of vehicles on motorways in different situations. The data from the detection loops cannot be used to determine the speed per vehicle. Therefore, this analysis examines the effect of road closure and detour signs and announcements on the total hourly traffic. The speed for each defined section of the motorway, Figure 46, is then analysed on the same days as the ANPR cameras. These are the Tuesday evenings of 27 February 2024, 5 March 2024, 12 March 2024 and 19 March 2024, with the Hagenweg closure taking place on 7 February and 12 March.

Pre-closure phase: The results for the average speed for the different days during the pre-closure phase are shown in Figure 58 and Figure 59. There are no noticeable changes in average speed for these days, and over the whole section, the speed varies around the average speed found for 2024. A higher speed was recorded on 5 March on section 2. However, there were no traffic signs indicating the closure on that day, so this does not indicate any different behaviour during a detour. On 12 March, a velocity was measured in section 3 that was equal to the minimum average speed found in 2024. However, this was not observed on the other closure day, 27 February.

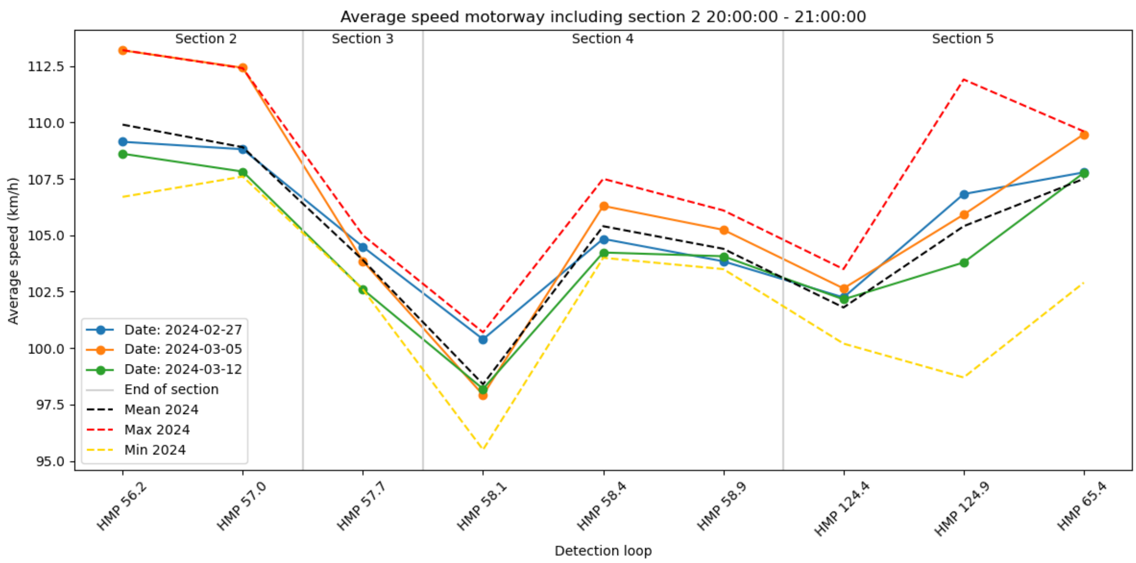

Figure 58: Average speed over different sections of the motorway Pre-Closure

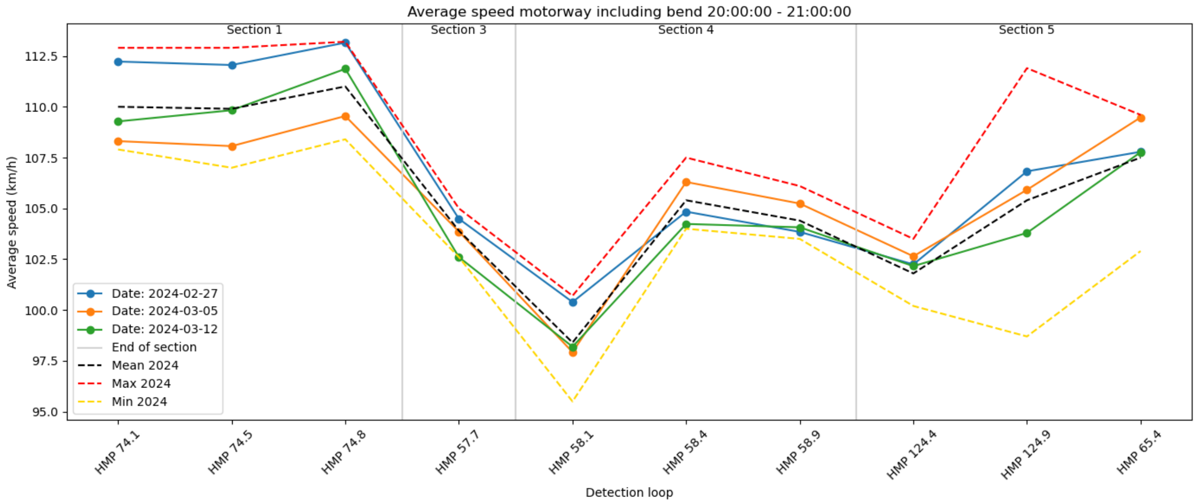

Figure 59: Average speed over different sections of the motorway Pre-Closure

Closure phase: The Hagenweg is closed between 21:00 and 04:00 on 27 February and 12 March 2024. Firstly, the period from 21:00 to 22:00 is considered as this is the period with the highest traffic volumes. For each motorway section, the results are compared with the average value corresponding to that section in 2024. The results are shown in Figure 61 and Figure 60. In addition, the results per section are compared with the expected hypothesis shown in Table 40. By analysing the results for each section, it can be determined whether the total traffic adopts a different speed when seeing a detour announcement.

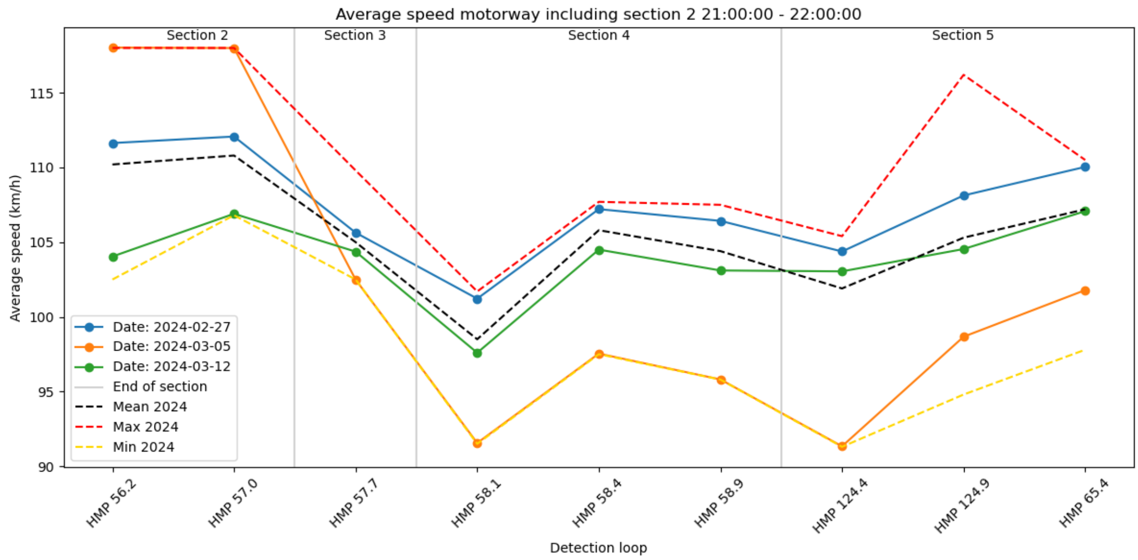

Figure 60: Average speed over different sections of the motorway

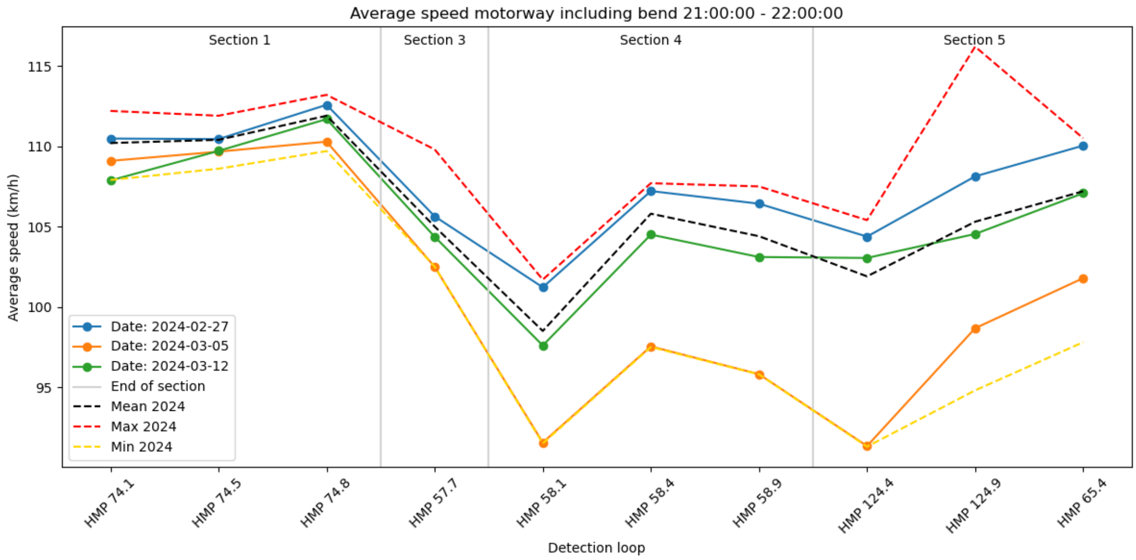

Figure 61: Average speed over different sections of the motorway

Overall speed motorway
Firstly, the speed found on the measurement days was compared with the average speed over the total section of the motorway. An outlier was identified from section 4 onwards, on 5 March 2024. The speed was much lower than the average and the other recorded speeds. However, on 5 March there was no detour and no closure of the Hagenweg. Therefore, the low speed cannot be a reason for the closure that took place for this study. The speed recorded on 5 March is therefore not representative and will not be considered further in this study. The other speeds recorded on 27 February 2024 and 12 March do not show any major differences from the average speed over the entire stretch of the motorway.

Section 1
In Figure 61 section 1 is shown. It can be seen that the speed on 5 12 March is slightly below the average speed. It is notable that the minimum speed seen at HMP 74.1 in 2024 is seen on 12 March. At HMP 74.1 there is the announcement sign Figure 13b. The low speed may indicate that the speed was reduced slightly to read the announcement. However, the differences are small and the speed in the rest of the curve is not much slower, so it is not possible to draw a direct conclusion from these results. The hypothesis for section 1 for speed differences, that behaviour remains the same, appears to be consistent with the results found.

Section 2
In section 2, Figure 60, the traffic speed is lower than the average speed found in 2024 and the speed found at HMP 57.0 is the minimum. In section 2 the detour is announced and information about the closure is given, which could be a reason for the lower speed. However, on 27 February, when the same traffic signs are present, the average speed is slightly higher than the average speed in 2024. Therefore, the same traffic sign situation shows opposite behaviour, and no specific conclusion can be drawn about the influence of traffic signs on the speed behaviour of the total traffic. Other factors, as discussed in subsection 4.3, may also be the reason for the difference in speed. The hypothesis for section 2 for speed differences, that behaviour remains the same, cannot be fully supported by the results found. Due to the different responses on the two measurement days, no explanation can be given for this time period.

Section 3
As there was only one measurement in section 3 with one detection loop, any changes in speed can only be considered on the basis of one point. The speed found on both days has a very small difference compared to the mean and therefore no speed changes can be seen. However, it was hypothesised that speeds should decrease in this section, but this effect is not seen in these results.

Section 4
The Hagestein exit and ramp are located in section 4 of the motorway. At the bottom of the Hagestein exit, the Hagenweg will be closed on 27 February and 12 March. This means that if traffic wants to use this exit, it will have to continue to the next exit, as indicated on the signs. It is hypothesised that following the signs will reduce the speed on this section of the motorway. It is expected that the decision on whether or not to follow the detour will be made at the last moment. As there is no visible construction on the motorway and the exit itself is open, the brainstorming session, subsection C.3,

suggested that the traffic may be more doubtful, which would reduce the speed in this section.

The results for the two measurement days do not show a clear decrease in speed. The speed on 27 February, as in the other sections, is even slightly higher than the average. Around the exit, the speed difference with the average is even greater than with the maximum speed. However, on both days the speed at the exit is slightly lower than on the other sections and after the exit, it is slightly higher again.

Section 5
Finally, there is no difference in the average speed on section 5 for 27 February compared to the other sections. For 12 March there is a slight difference in the speed drop around the Nieuwegein exit. In this case, the speed remains more constant compared to the detection loop HMP 58.9, whereas in the other measurements, a small speed drop can be seen when approaching the exit. The hypothesis for this speed is that there would be a decrease in speed. However, the results do not show this and on 12 March there is even less change in speed around the exit ramp.

Average traffic speeds were also analysed for the remaining periods to assess the impact of the closure and traffic signs on overall motorway traffic. The average hourly speed measurements show that on the night of 12-13 March, when there was no closure for the study, the speed is lower than on the other days and also shows a large difference compared to the average from section 4 onwards. There were no special weather conditions on any of the four measurement days, which were dry with limited wind. This trend is found for all the measured time periods. An example of the differences is shown in Figure 62. The other time periods are shown in in Table 71 in Appendix K. As a result, the values found for the night of 12 to 13 March are not representative and cannot be used as a baseline study to assess whether traffic reacts differently during a closure than under normal conditions.

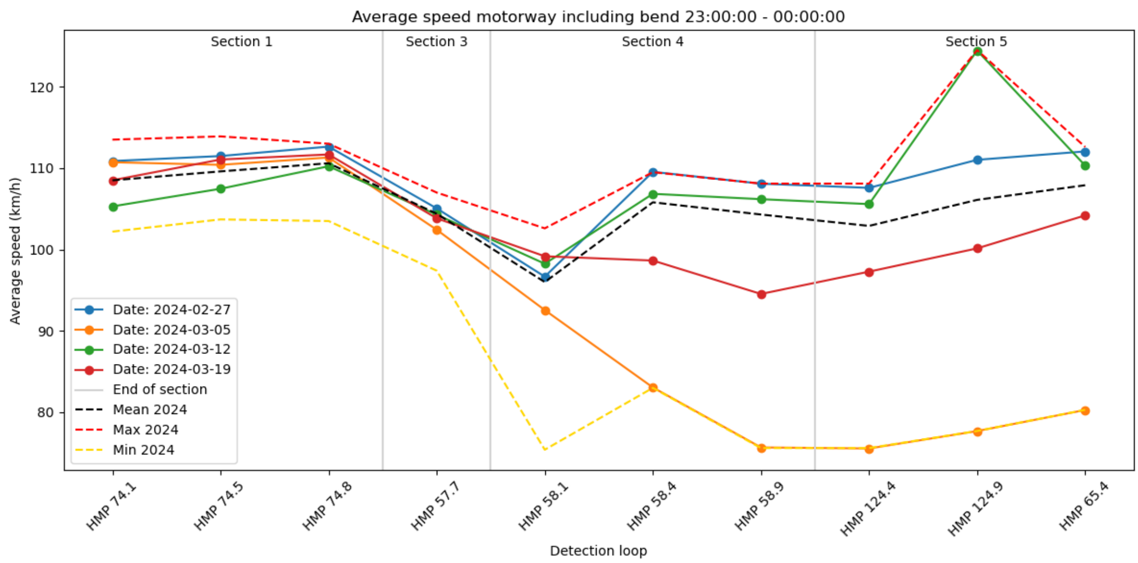

Figure 62: Average speed 23-24

The results for 19 March also show a difference compared to the other average speeds measured. The speed for sections 4 and 5 is lower compared to the average speed. Another remarkable effect can be seen in section 5 of the 12 March measurement, where the average speed jumps up around the Nieuwegein exit. This effect is also visible for the following period from 24:00 to 01:00, but not afterwards. There are also more speed differences at different locations during the night hours (shown in Table 71 in Appendix K). However, there is no clear trend around decision points or traffic signs.

Post-closure: The total average speed measured on different sections of the motorway can give an indication of how traffic responds to traffic signs. However, because it is an overall average, it is not possible to see the difference between the time when the road is closed the time when the signs are removed and the time when the road is still closed.

In Figure 63 and Figure 64 shows the results of the average speed of traffic on the A27 motorway section. The measurements did not give a consistent indication of the average speed on the closure days. There is no pattern of constant speed reduction or increase. However, the Hagestein exit showed a smaller speed drop on 13 March than on the other days. This is not visible on 27 February, so it cannot be said with confidence that this is due to the traffic measurements around Hagenweg.

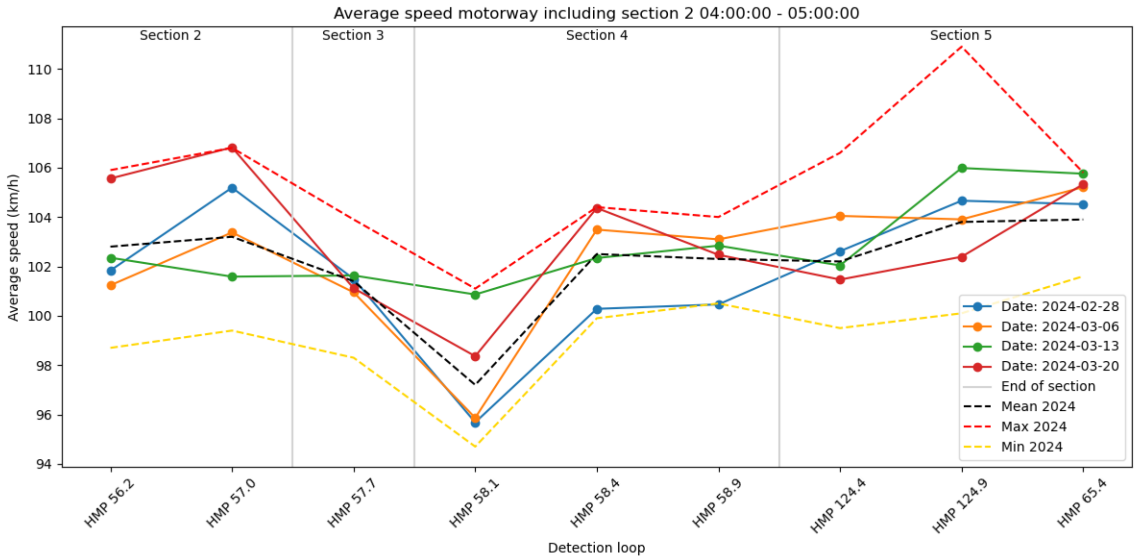

Figure 63: Average speed A27 post-closure phase

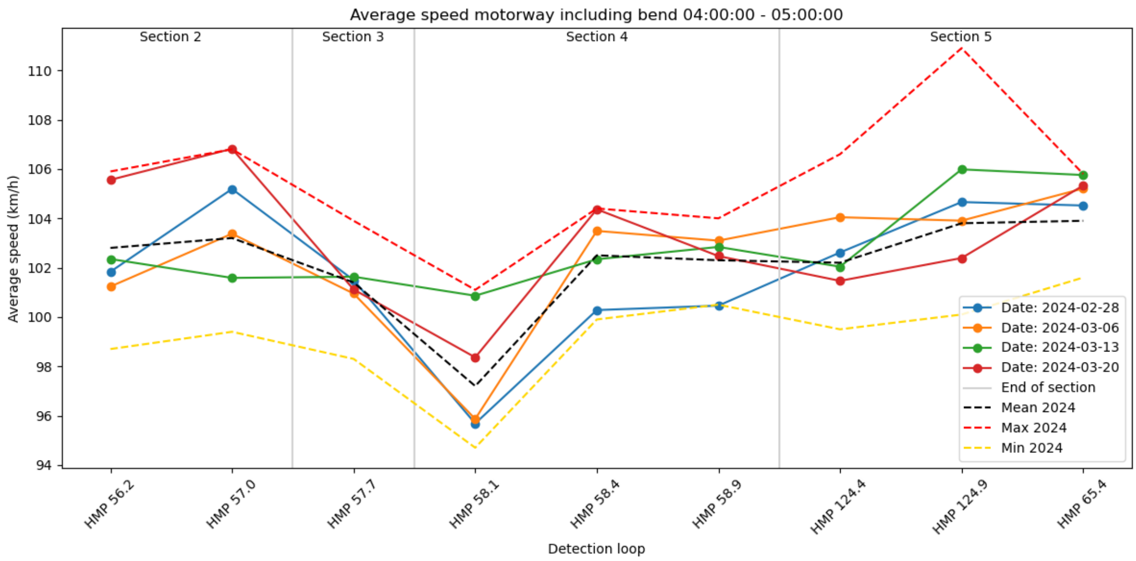

Figure 64: Average speed A27 including bend post-closure phase

6.3.5 Statistical chi-squared analysis

The chi-squared method is used to determine whether the behaviour on the motorway is significantly different from the expected situation. A null hypothesis is used to determine whether there is a significant difference. In the case of traffic volume, the null hypothesis is that the expected traffic volume on the different detection loops is equal to the average value found in 2024. For the average speed, a similar null hypothesis is used, except that it is the average value found for the average speed in 2024. The chi-squared values are determined for the time period and for the different detection locations. For the time period the critical value is equal to 19.675. For the detection location the corresponding critical value is equal to 15.507.

Traffic volumes

Table 42 and Table 43 show the results of the statistical analysis for the traffic volumes on the A27 motorway. It can be concluded that the hourly traffic volumes from 20:00 to 01:00 on 27 February are significantly different from the average situation in 2024. Per location, the values differ significantly from the average up to the point where section 1 and section 2 converge. For the measurements on 12 and 13 March, the traffic volumes for 20:00 - 01:00 and 03:00 - 04:00 are significantly different. At each detection location, the number of vehicles differs significantly from the average found in

2024.

Table 42: Statistical chi-squared analysis Traffic volumes 27-28 February A27

	Statistical analysis χ^2 A27 traffic volumes 27-28 February												
Time period	**74.1**	**74.5**	**74.8**	**56.2**	**57.0**	**57.7**	**58.1**	**58.4**	**58.9**	**124.4**	**124.9**	**65.4**	$\sum\chi^2$ **Time period**
20-21	10.753	11.117	11.790	39.722	38.367	2.689	3.203	3.191	5.017	3.889	4.977	6.171	140.89
21-22	31.883	32.916	32.523	10.204	9.879	4.375	5.116	5.046	2.536	1.565	1.169	1.596	138.81
22-23	7.253	5.190	7.132	0.252	0.090	2.031	2.849	1.982	2.116	1.567	1.756	1.514	33.73
23-24	1.037	2.438	1.883	11.509	10.917	0.740	1.059	1.441	1.237	0.520	0.406	0.222	33.41
24 01	3.041	7.803	7.092	1.753	2.473	0.083	0.271	0.000	0.306	0.012	0.032	0.000	22.87
01 02	0.011	0.095	0.266	1.020	0.827	0.046	0.046	0.194	0.018	0.170	0.135	0.000	2.83
02 03	0.225	0.056	0.056	0.371	0.375	0.290	0.024	0.006	0.022	0.051	0.025	0.006	1.51
03 04	1.532	0.620	0.605	0.438	0.441	0.046	0.082	0.202	0.005	0.046	0.024	0.055	4.10
04 05	2.075	2.955	3.114	2.030	1.306	0.024	0.011	0.046	0.042	0.131	0.164	0.055	11.95
$\sum\chi^2$ **Location**	57.81	63.19	64.46	67.30	64.68	10.32	12.66	12.11	11.30	7.95	8.69	9.62	390.09

Table 43: Statistical chi-squared analysis Traffic volumes 12-13 March A27

	Statistical analysis χ^2 A27 traffic volumes 12-13 March												
Time period	**74.1**	**74.5**	**74.8**	**56.2**	**57.0**	**57.7**	**58.1**	**58.4**	**58.9**	**124.4**	**124.9**	**65.4**	$\sum\chi^2$ **Time period**
20-21	24.07	25.66	23.85	38.65	38.90	0.16	0.29	0.38	0.16	0.18	0.00	4.72	157.01
21-22	11.37	10.07	11.11	157.57	158.06	35.36	36.86	36.38	23.09	24.76	17.42	22.59	544.65
22-23	23.67	24.51	23.27	166.37	169.85	21.46	23.39	22.02	22.13	22.63	19.42	18.41	557.13
23-24	9.01	7.54	8.12	51.61	53.80	4.71	4.07	4.60	6.06	6.17	6.72	5.14	167.56
24 01	7.97	14.68	17.23	0.11	0.55	6.73	6.47	6.99	5.65	6.01	8.42	9.62	90.45
01 02	2.75	2.06	2.09	0.00	0.37	1.01	1.31	0.91	1.65	1.89	0.65	0.55	15.23
02 03	0.35	1.13	0.35	0.16	0.17	0.29	0.15	0.06	0.05	0.01	0.01	0.03	2.74
03 04	0.46	0.32	0.31	2.89	3.25	2.49	3.22	5.75	5.47	4.88	5.79	6.68	41.52
04 05	0.21	0.09	0.02	0.25	0.33	0.00	0.00	0.10	0.21	0.52	1.77	0.99	4.49
$\sum\chi^2$	79.86	86.05	86.35	417.62	425.28	72.20	75.78	77.18	64.48	67.04	60.20	68.73	1580.78

Average speed
The average speed on the motorway on the days when Hagen Road was closed was also tested to see if it was significantly different from the average speed in 2024. For the two nights of 27-28 February and 12-13 March, the results are shown in Table 44 and Table 45. By time period and detection location, the values are not significantly different from the average speed found in 2024. This does not reject the null hypothesis that the speed is similar to the average speed in 2024.

Table 44: Statistical chi-squared analysis average speed 27-28 February A27

	Statistical analysis χ^2 A27 average speed 27-28 February												
Time period	**74.1**	**74.5**	**74.8**	**56.2**	**57.0**	**57.7**	**58.1**	**58.4**	**58.9**	**124.4**	**124.9**	**65.4**	$\sum\chi^2$ **Time period**
20-21	0.044	0.040	0.044	0.001	0.000	0.002	0.041	0.003	0.003	0.002	0.019	0.001	0.1996
21-22	0.001	0.000	0.004	0.018	0.015	0.003	0.074	0.019	0.038	0.061	0.074	0.073	0.3814
22-23	0.023	0.020	0.013	0.020	0.070	0.000	0.045	0.046	0.043	0.157	0.116	0.173	0.7269
23-24	0.053	0.030	0.036	0.193	0.082	0.005	0.007	0.137	0.138	0.215	0.226	0.156	1.2767
24 01	0.080	0.122	0.102	0.108	0.058	0.088	0.191	0.124	0.197	0.141	0.161	0.157	1.5297
01 02	0.174	0.030	0.102	0.038	0.102	0.005	0.078	0.005	0.154	0.020	0.039	0.086	0.8315
02 03	0.018	0.025	0.047	0.209	0.145	0.064	0.209	0.005	0.015	0.010	0.017	0.000	0.7637
03 04	0.029	0.274	0.233	0.294	0.006	0.007	0.187	0.004	0.000	0.189	0.078	0.036	1.3379
04 05	0.034	0.006	0.002	0.010	0.039	0.000	0.003	0.047	0.032	0.002	0.008	0.003	0.1856
$\sum\chi^2$ **Location**	0.457	0.548	0.584	0.889	0.517	0.175	0.835	0.389	0.620	0.795	0.739	0.686	7.2330

Table 45: Statistical chi-squared analysis Average Speed 12-13 March A27

	Statistical analysis χ^2 A27 Average speed 12-13 March												
Time period	**74.1**	**74.5**	**74.8**	**56.2**	**57.0**	**57.7**	**58.1**	**58.4**	**58.9**	**124.4**	**124.9**	**65.4**	$\sum\chi^2$ **Time period**
20-21	0.004	0.000	0.007	0.006	0.011	0.019	0.000	0.014	0.001	0.002	0.024	0.001	0.089
21-22	0.052	0.004	0.000	0.349	0.137	0.003	0.008	0.016	0.016	0.012	0.006	0.000	0.605
22-23	0.040	0.003	0.011	0.389	0.026	0.000	0.023	0.016	0.022	0.012	1.249	0.041	1.832
23-24	0.094	0.040	0.001	0.018	0.000	0.000	0.060	0.011	0.035	0.071	3.156	0.053	3.541
24 01	0.202	0.027	0.058	0.016	0.013	0.008	0.291	0.002	0.008	0.000	0.584	0.008	1.218
01 02	0.093	0.210	0.096	0.063	0.049	0.000	0.015	0.040	0.006	0.005	0.003	0.008	0.590
02 03	0.251	0.309	1.290	1.194	0.137	0.000	1.000	0.486	0.020	0.004	0.000	0.062	4.754
03 04	0.878	0.216	0.002	0.449	0.634	0.209	0.278	0.006	0.045	0.002	0.005	0.029	2.754
04 05	0.000	0.034	0.049	0.002	0.025	0.000	0.141	0.000	0.002	0.000	0.039	0.035	0.327
$\sum\chi^2$ **Location**	1.616	0.844	1.516	2.486	1.034	0.241	1.817	0.592	0.155	0.107	5.067	0.237	15.711

6.4 Results Case Study A27

The different sub-analyses examined the behaviour of vehicles observed around the closure for three different phases: pre-closure, closure and post-closure. The phases were analysed using ANPR cameras and detection loops to assess the routes taken by vehicles around the closure and their behaviour on the motorway around the traffic signs.

The ANPR cameras were used to determine the routes taken by the vehicles. The analysis went through several steps to finally determine the route selections. The percentages of route choices for both nights are shown in Figure 65.

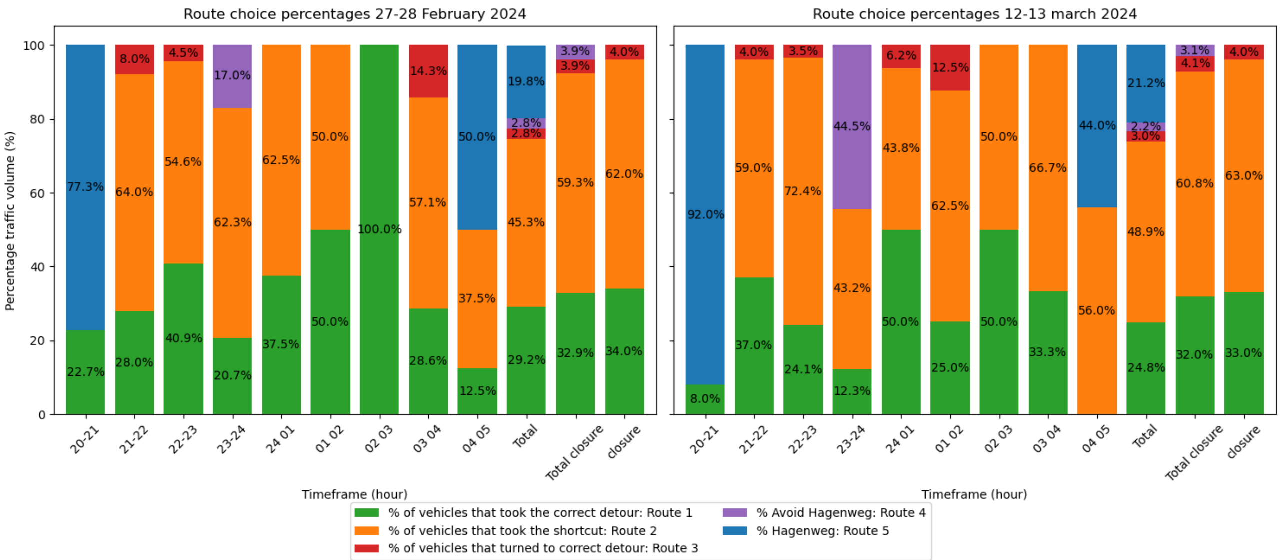

Figure 65: Proportion route choices by closure Hagenweg
Total closure: total route choices during closure phase 21:00 - 04:00
closure: route choices during closure phase detected vehicles 21:00 - 04:00

Hourly route choices were determined for all three phases and multiple time periods. The pre-closure phase is the period between 20:00 and 21:00. During this period, the Hagenweg was not closed and traffic signs along the motorway were visible to traffic during the hour. On both days, no vehicles were seen on Routes 2, 3 and 4 during these periods. This can therefore be explained by the fact that Hagenweg was open so that those travelling that way did not encounter any obstacles. There is a difference between the percentages of vehicles seen on Route 1 on both days, and one reason for this difference could be that the road signs were visible to traffic at different times. When the signs were visible earlier on 27-28 February, there was also a longer period of time when vehicles could follow the detour via Route 1. However, these times are not known and this reason remains an assumption.

The closure phase lasted from 21:00 to 04:00 on both nights. This phase was considered on an hourly basis and the hours between 21:00 and 04:00 were considered as a total (Total closure). This was also done for the total number of vehicles detected during these hours (closure). The differences between the total closure and the closure are small because the proportion of vehicles avoiding Hagenweg by staying home or taking another route is likewise limited. In addition, the overall percentages found for both nights are very similar. This shows that a large proportion of vehicles around a closure do not use the detour and do not follow the information from the traffic signs on the motorway. In total, circa 33% of vehicles follow the detour signs and 64% of vehicles not follow up the detour. However, out of these 64%, 4% turn back to the indicated detour when they see the closure. The remaining 4% are vehicles that avoid the closure by staying at home or taking another route.

During the hours of the night closure, the number of vehicles seen on the routes decreases, so the percentages of route choices are also based on smaller numbers. For most periods more vehicles do not follow the detour than do, except 28 February between 02:00 and 03:00. In this time period, 100% of the vehicles followed the detour, but it only consisted of 1 vehicle. The hours do not show the same pattern, but this may be due to the number of vehicles detected during these hours. Due to the small volumes, an additional vehicle on one of the routes has a big impact on the percentages of route choices.

The post-closure phase took place during 04-05. The road closure was cleared at 04:40 on both days and the signs were removed immediately afterwards. For the first 40 minutes of the hour, Hagenweg will be closed and vehicles will be advised to follow the detour. The Hagenweg will be reopened for the last 20 minutes. As no measurements have been taken on the Hagenweg, it is not possible to determine how many vehicles have used it during these minutes. Therefore, it is not possible to make a detailed analysis of traffic behaviour when the closure is lifted but the traffic signs are still in place. As a result, the route choice percentages are based on the expected number of vehicles and the vehicles seen on the routes. On 12 and 13 March, no vehicles continued their journey via Route 1, the Nieuwegein exit.

In addition to the ANPR measurements, a number of evaluations were carried out using measurements from the detection loops on the motorway. For a number of periods, the observed traffic volume is higher than the average value. On 27 and 28 February this results in higher volumes at the Nieuwegein exit until 24:00 and up to 2 hours on 12 and 13 March. At the Hagestein exit, the observed differences are smaller and only visible on 12 March until 23:00. These higher numbers may contribute to a higher number of vehicles taking a different route than normal due to the closure of the Hagenweg. This may lead to small changes in the percentage of vehicles following the detour, but the differences are expected to be small. This is because there were no major differences from the measured value on 19 March for vehicles taking a different route. The same applies to the expected values of the vehicles.

The average speed per hour was also determined and analysed for different sections of the motorway. The average speeds found around traffic signs and exits show no clear trend for all phases and periods.

7 Evaluation Detour Behaviour Model

In section 4 the Detour Behaviour Model was presented. The model is based on expert interviews, brainstorming sessions and literature. In this chapter, the Detour Behaviour Model will be validated using the results from the two case studies, section 5 and section 6.

The validation process will focus on the different components of the model. First, the detour decision factors component will be examined, in particular the measurable contextual and economic factors. This is followed by validating the detour driver profiles identified in the model against the case study results by identifying which driver profiles are represented in these results. Finally, the expected driving patterns around the road closures will be compared with the actual driving patterns observed in the case studies.

In subsection 7.4 the results of both case studies are evaluated and compared in relation to the Detour Behaviour Model. The comparison between the case studies and the detour behaviour model will help to evaluate the applicability of the model to road closures and its potential to facilitate comparisons between different situations. The final section, subsection 7.5, will deal with the evaluation of the model design. This evaluation aims to determine the extent to which the model accurately represents different scenarios that may arise around road closures and to identify any missing components or areas for improvement.

7.1 Detour decision-making factors

In subsection 4.3 there are three categories of factors that are identified as factors in detour behaviour. From these two categories, the two measurable categories, contextual and economic factors, are examined for the two observations of the A9 and A27 case studies. The corresponding factors are given in Table 46.

The differences between the factors are mainly between the rain conditions for the A9 case study and the difference in the speed limit on the motorway. On the A9 there is a lower speed limit during the works due to the closure of one lane. However, there are no visible works. In addition, the proportion experiencing inconvenience due to road closure is higher for the A9 case study than for the A27 case study. In terms of economic factors, the additional costs in terms of vehicle hours lost are higher for the A9 than for the A27 case study due to the higher number of traffic volumes affected by the incident and the only slightly lower diversion time.

Table 46: Detour model evaluation factors

		A9 Case study		**A27 Case study**	
		6-7 February	**8-9 February**	**27-28 February**	**12-13 March**
Contextual factors					
Road conditions		Good	Good	Good	Good
Light conditions		Night	Night	Night	Night
Weather conditions		Rainy	Rainy	Normal	Normal
Speed limit		70 km/h	70 km/h	100 km/h	100 km/h
Construction activity status		No activities visible	No activities visible	No activities visible	No activities visible
Traffic congestion		No delays	No delays	No delays	No delays
Time of the day	Pre-closure	19:00 - 20:00	19:00 - 20:28	20:00 - 21:00	20:00 - 21:00
	Closure	20:00 - 04:18	20:28 - 03:05	21:00 - 04:00	21:00 - 04:00
	Post-closure	04:00 - 05:00	03:00 - 04:00	04:00 - 05:00	04:00 - 05:00
Number of lanes		3	3	2	2
Traffic volumes	**Motorway**	High	High	High	High
	Ratio*	10 - 50%	6-31%	1-4%	1-6%
Economic factors					
Time differences		6 - 8 minutes	6-8 minutes	4-6 minutes	4-6 minutes
Extra costs		€1438.33	€1495	€128.33	€156.67
Distance difference		7.8 km	7.8 km	5.3 km	5.3 km

* Ratio: volumes vehicle motorway and number expected vehicles closure road

7.2 Detour driver profiles

For both case studies, the route choices observed from vehicles around the closed road were analysed. It is possible to identify which driver profiles were observed in both case studies using the route choice analysis.

For the A9 case study, a distinction was made between vehicles that took the exit road despite the closure and did not follow the traffic signs, forcing them to turn around at the roundabout at the end of the exit road. The vehicles observed for this route action belong to driver profile 2. They do not follow the detour. The remaining vehicles cannot be further differentiated for this study. However, the vehicles have at least partially followed the information by not taking the exit due to the closure and are therefore all classified as Driver Profile 1. For the A27 case study, the route analysis consisted of analysing the routes around the closure, including a shortcut and the correct detour. From these observations, it is possible to identify which drivers do or do not take the detour, which vehicles take a different route and, by comparing this with the expected numbers, whether there are any vehicles avoiding the closure. All four driver profiles were identified. The route analyses for the two case studies determined the percentage of vehicles taking a particular route. This allows the identification of which driver profiles were observed during the two case studies, the results of which are presented in Table 47. However, it should be noted that the vehicles on the A27 in the case study took a different route after taking the exit onto the closed road. Consequently, these vehicles do not follow the temporary roadworks signs. It can therefore be said that Driver Profile 3 in the A27 case study is part of Driver Profile 2.

Table 47: Detour driver profiles percentages found in case study A9 and A27 between 21:00 and 04:00.

Driver profiles	**Case study A9**		**Case study A27**	
	6-7 February	**8-9 February**	**27-28 February**	**12-14 March**
Driver profile 1: Following detour*	24.8 - 93.3%	6.7 - 75.2%	32.9%	32.0%
Driver profile 2: Not following detour	24.5 - 87.5 %	12.5 - 75.5%	3.9%	4.1%
Driver profile 3: Choosing another route**	-	-	58.3%	60.8%
Driver profile 4: Avoiding closure location	-	-	3.9%	3.1%

* Case study A9, driver profile 1 includes vehicles that do not take the exit to the closed road, but it is not known if they follow the associated detour.

** Case study A27, driver profile 3: Follows shortcut but does not follow detour

7.3 Driving patterns around detours

After defining the driver profiles, several scenarios of driving patterns that could occur around a road closure were set up in subsection 4.6, with accompanying information and detours indicated on the motorway. In both case studies, a road on the secondary road network of the motorway was completely closed. This resulted in 20 possible scenarios, which are shown in Figure 17. The results of the two case studies were used to compare expectations with observed driving patterns. Route choice was analysed using traffic measurements from the ANPR cameras.

Pre-closure phase

For the A9 case study, it is not possible to determine from the measurement results what percentage of drivers are already following the detour or who is not following the measures in the pre-closure phase. For this reason, this phase was excluded for the A9 based on the derivation of the observed scenarios. The A27 case study, however, allows to determine whether vehicles are taking the indicated detour and whether they are making a different choice. Vehicles were seen to take the detour on both days during the pre-closure period. Moreover, if they do not follow the signs and take the exit, there are no consequences. The situations observed were, therefore, no change in driving behaviour, not following the detour and following the detour. In the situation where some of the signs are visible, there was no possibility to measure the corresponding driving behaviour. Therefore, scenario 2 was not possible to observe. In addition, it was not possible to determine at what time in the hour the vehicles were detected, making it impossible to distinguish between scenarios 1 and 6, 3 and 4. For this reason, it was decided to consider all four scenarios as observed. The results of scenarios examined for both case studies are shown in Table 48

Table 48: Pre-closure scenarios

Pre-closure scenarios	Case study A9		Case study A27	
	6-7 February	**8-9 February**	**27-28 February**	**12-13 March**
Scenario 1: No changes in driving behaviour	-	-	x	x
Scenario 2: Following traffic signs (partly)	-	-	-	-
Scenario 3: Following signs	-	-	x	x
Scenario 4: Follow detour	-	-	x	x
Scenario 5: Another detour	-	-	x	x
Scenario 6: Not following detour	-	-	x	x

x = Observed in measurements   - = Not observed in measurements

Closure phase

The possible scenarios around the closure phase are divided into three locations, the Announcement Area, the Start Detour Area and the Road Closure Area. The announcement area and the start detour area are located on the motorway, so in the case study measurements at these locations cannot be used to analyse which scenarios occur. However, they can be identified from the results of the measurements. For the A9 case study, scenarios 7, 9, 10, 12 and 16 can be detected by distinguishing with the ANPR cameras whether or not the exit is taken and returned to the motorway when the road is closed. Scenario 14 is not detectable for the case study as there is no shortcut available at the road closure area. The results of the ANPR camera measurements identified that all possible scenarios are detected for the A9 case study. For the A27 case study, ANPR camera measurements can also be used to determine whether scenarios have occurred. It is therefore also possible to analyse whether vehicles have diverted and whether there is a shortcut around the road closure. All scenarios can be identified and the results show that they have all occurred. Vehicles were detected on the detour, on the shortcut and vehicles that turned back to the correct detour. The results of examined scenarios for the closure phase are shown in Table 49.

Table 49: Closure scenarios

Closure scenarios	Case study A9		Case study A27	
	6-7 February	**8-9 February**	**27-28 February**	**12-13 March**
Announcement Area				
Scenario 7: Follow detour	x	x	x	x
Scenario 8: Another detour	-	-	x	x
Scenario 9: Not following detour	x	x	x	x
Start detour				
Scenario 10: Follow detour	x	x	x	x
Scenario 11: Another detour	-	-	x	x
Scenario 12: Not following detour	x	x	x	x
Road closure area				
Scenario 15: Shortcut	-	-	x	x
Scenario 16: Moves back to detour	x	x	x	x

x = Observed in measurements   - = Not observed in measurements

Post-closure phase
At the end of the closure, the signs will be removed, but vehicles may or may not follow the detours indicated by the signs if they are still visible. The results of the scenarios examined for both case studies in the post-closure phase are shown in Table 50. The ANPR measurements of the A9 case study shows on both measurement days that vehicles are still returning towards the motorway. This indicates that the road is still closed during these moments. It is not possible during the post-closure measurements to distinguish when the road is open or not. Therefore it is decided to consider all scenarios as observed. The same applies to the A27 case study where the hour could not be split. However, on 12-13 March, no vehicles were seen on the detour during the post-closure period, therefore Scenarios 20, 21 and 22 are not observed during this night.

Table 50: Post-closure scenarios

	Case study A9		Case study A27	
Post-closure scenarios	**6-7 February**	**8-9 February**	**27-28 February**	**12-13 March**
Scenario 19: No changes in driving behaviour	x	x	x	x
Scenario 20: Following traffic signs (partly)	x	x	-	-
Scenario 21: Following signs	x	x	-	-
Scenario 22: Follow detour	x	x	-	-
Scenario 23: Another detour	x	x	x	x
Scenario 24: Not following detour	x	x	x	x

x = Observed in measurements - = Not observed in measurements

Speed adjustments motorway
Behaviour on the motorway was analysed using the average speed of all traffic for each closure phase. The speed changes are not defined by scenario. However, the speed has been analysed against the three main most likely changes: decrease in speed, no change in speed and increase in speed.

For the different phases, no difference was found in the speed changes of the traffic on the motorway. However, it is observed that there are more speed differences between days during the night hours. For the A9 case study it is observed that the average speed of the traffic is lower on the days when the Schipholweg is closed. The speed is lower than the average speed in 2024, but the speed limit on these days was not 100 km/h, but 70 km/h. The reason for the lower speed limit was the closure of a motorway lane. However, the average speed observed on the measurement days is higher than the new speed limit and lower than the normal speed limit and average speed. Moreover, it cannot be determined whether the speed reduction or increase is also influenced by the closure of the Schipholweg. For the case study on the A27, it varies from hour to hour whether the speed is higher or lower than the average speed found in 2024. The posted speed limit on the A27 is 100 km/h, but the average speed driven is higher than this limit, as shown in subsection 6.3. In addition, there are no significant differences in the speed driven on days when the Hagenweg is closed compared to days when it is not.

7.4 Evaluation results observation study using detour behaviour model

Following the previous sections' examination of the model aspects of detour behaviour in the two case studies, a comparative analysis is carried out to compare aspects of the model. The purpose of this examination is to determine whether the combination of these aspects produces specific results and to identify differences between the case studies.

For both case studies, the associated factors, driver profiles and driving patterns around the road closure were examined. There are differences between the A9 and A27 case studies in terms of detour factors, the speed limit, the ratio of vehicles affected by the closure to the number of vehicles on the motorway, and the cost of the closure. There were also differences in the number of vehicles that did not follow the detour between the two case studies. This may be due to differences in the factors between the two case studies. For example, the slower speed on the motorway may mean that there is more time to process the information from the detour signs, and it may also be clearer that there is a closure. However, observations do not allow us to find out what motivates drivers in the vehicles to make certain choices, so the effect of different factors cannot be studied in detail.

Between the two case studies, there is a difference in the number of ANPR cameras used, which affected the number of routes that could be analysed around the detour. This difference in camera deployment led to differences in the observed driving patterns for each case study. In particular, route choice could be more clearly distinguished for the A27, resulting in more driver profiles being observed compared to the A9 case study. The number of vehicles using the information to continue on the A9 is included in Driver Profile 1. This shows that traffic that took the exit and then had to turn around either did not use the information from the signs or did not observe or understand the signs and are included in Driver Profile 2. For the A27, there is a clearer distinction in route choice. The availability of a shortcut on the secondary road network immediately after the exit in the A27 case study, which is not available on the A9 case study, resulted in fewer vehicles returning to the motorway. However, it remains unclear whether the vehicles that took the shortcut were informed by the signs and chose the alternative route, or whether they discovered the closure unexpectedly and then took the shortcut that connected to their current route.

From the observations, the detour model can be used to provide insights into the choices visible around road closure and associated detour made by road users, but the method cannot provide insights into the motivations associated with the factors of the model and the specific choices made. Hence, the results of the two case studies can each be correlated with the established model of detour behaviour. Differences in the number of vehicles following or avoiding a detour were observed between the two case studies, due to differences in the factors and measurement methods used. Nevertheless, the model is able to capture more detailed distinctions between the case studies by using the additional detour factors that are identified. However, for the observations only the measurable factors could be included in the model.

7.5 Evaluation design Detour Behaviour Model

By examining the various aspects of the detour model along with the results of the case studies, the design elements involved can be analysed. Furthermore, these findings will be used to assess the comprehensiveness of the detour behaviour model in capturing the complexities and challenges associated with closures.

The contextual and economic factors can be determined from measurements, but the personal characteristics and psychological factors cannot, and to make them usable in the model this needs to be further specified. To further qualify these, detailed information is needed about road users on the road.

Four different driver profiles were identified and observed. Despite Driver Profile 2 being categorised as not following a detour, it was observed that Driver Profiles 3 and 4 also deviated from the detour making a different choice. This implies that when distinguishing between following and deviating from a detour, driver profile 1 should be considered as following the detour, while a combination of profiles 2, 3 and 4 should be considered as not following the detour.

Furthermore, while it is relatively straightforward to identify vehicles following an alternative route through measurements, identifying those not following the detour and choosing an alternative route is challenging. In this study, a distinction was made between these two categories by defining vehicles that disregarded the signs and had to turn around due to the closure as belonging to Driver Profile 2, while vehicles that were not directly observed were assumed to be in line with Driver Profile 4. Therefore, the justification for Driver Profiles 2 and 4 should therefore be defined in the case that the model is applied.

The results of the case studies show that the different scenarios are identifiable when considering the traffic flows around a detour, where it is important to use shorter than hourly periods to distinguish between the pre-and post-closure situations. It is also important to consider that different scenarios may follow each other and that a decision to follow a detour may not result in it being followed.

8 Data validation

The analyses of driver behaviour have used multiple data sources and repeated measurements at different locations, on different days and over different time periods. This chapter assesses the quality and capabilities of these data sources, focusing on the NDW data and ANPR camera measurements. In addition, a comparison is made between these data sources. These analyses are based on the period between 21:00 and 22:00 in 2024. This period was chosen because it is the hour with the highest number of vehicles during the closure period.

A number of hypotheses were formulated to validate whether the data represented the correct information as expected, which are linked at the different motorway sections of the case studies, Table 51. The results found were additionally tested against the hypotheses drawn up for significance with statistical analysis. The following hypotheses have been formulated for this purpose:

1. The variations in the total measured traffic volumes per hour on a section of motorway without on- and off-ramps are not significant.
2. The difference in the number of vehicles passing through the detection loop just before and immediately after the exit (without another ramp) determines the number of vehicles using the exit ramp and is therefore not significantly different from the exit ramp measurements taken with the ANPR cameras.
3. The difference between the number of vehicles passing through the detection loop just before and immediately after the access ramp (no other ramp in between) determines the number of vehicles using the entrance ramp and is therefore not significantly different from the access ramp measurements taken with the ANPR cameras.

Table 51: Validation information NDW Traffic volumes

Hypothesis	**A27 Motorway**		**A9 Motorway**	
	Section	**Detection loop**	**Section**	**Detection loop**
1	Section 1 Section 2 Section 3-4 Section 4 -5	HMP 74.1, 74.5, 74.8 HMP 56.2, 56.6, 57.0 HMP 57.4, 57.7, 58.1 HMP 58.0, 124.4, 124.9	Before exit	HMP 30.8, 31.2
2	Section 4: Exit Hagestein Section 5: Exit Nieuwegein	HMP 58.1 - 58.4 HMP 124.4 - 124.9	Exit Aalsmeer	HMP 31.2 - 31.6
3	Section 4: Access Hagestein	HMP 58.4 - 58.9	Access Aalsmeer	HMP 31.6 - 32.0

8.1 NDW detection loop data

NDW data is obtained from the various detection loops on the motorway. The data from the detection loops can be retrieved using the Dexter tool as described at subsection 2.6. NDW data was used to analyse the behaviour of road users on the motorway around a diversion and closure. For this purpose, the average speed per hour, and the measured traffic volumes per hour were used. The measured traffic volumes on the motorway represent the number of vehicles per hour. To validate whether the data represented what was expected, the detection loops in the different sections of the A27 and A9 motorways were compared for hypothesis 1. The data in this section validated for the year 2024 for the period 21:00-22:00.

Hypothesis 1

The first hypothesis is validated on the basis of the different detection loops, between which no vehicles can choose another route and between which the traffic volume should remain constant. This analysis is carried out on a section-by-section basis to see if the data for each section are in line with expectations. This analysis is performed for the year 2024 for the period 21:00-22:00. To validate how consistent the traffic volumes are across the different detection loops, the difference between the loops was calculated and compared. Between the different loops, the difference in mean, median, minimum, maximum and value was determined. For the loops on the A27, the difference in value was also determined for the four Tuesdays on which measurements were made. For the A9 this was done for Tuesday 6 February and Thursday 8 February.

Section 1 A27

Section 1 of the A27 motorway is where traffic from the A2 turns onto the A27, see Figure 46. There are three different detection loops in the bend, all recording intensity and average hourly speed. There is no exit at the bend, which means that the traffic passing through this section must be the same for all loops. For 3 combinations of loops HMP 74.1 - 75.5, HMP 74.1 - 74.8 and HMP 74.5 - 74.8, the differences between the detection loops were determined. For example, the traffic volumes at detection loop HMP 74.1, 74.5 and 74.8 equals the values 467, 463, and 478 on 27 February 2024 between 21:00 and 22:00. The differences between these detection loops for this day and the other measurements are shown in Figure 66.

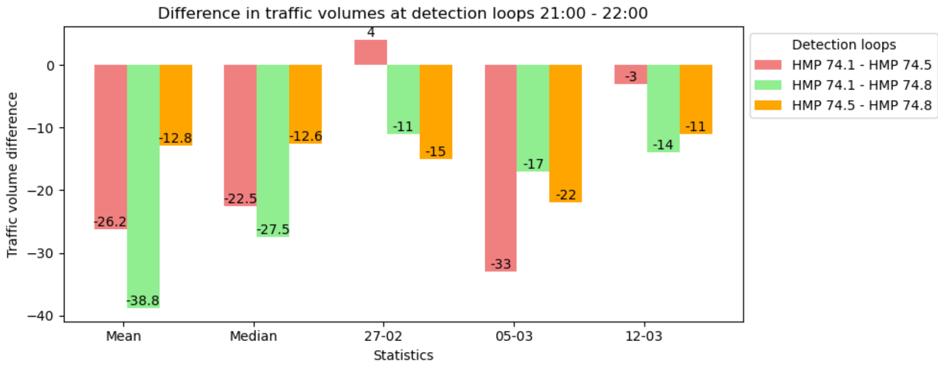

Figure 66: Difference in traffic volume in section 1 A27 between detection loops

The results show that in almost all cases there is a difference in the number of vehicles measured between the different detection loops. In addition, it can be seen that the difference in values does not show a clear correlation for the different measurements. However, it can be seen that the HMP 74.8 detection loop measures a higher or equal intensity compared to the other two detection loops, except for the minimum value in 2024. Based on the differences between the detection loops on a given day, it is a reasonable observation that the mean and median values are different between the detection loops. The same applies to the minimum and maximum values. However, for these two values, it is important that they are measured on the same days to estimate traffic. In the results in Figure 50, it can be seen that this is at least the case for the maximum value found on 03-05-2024, assuming that this is also the case for other days then since no large nodding shows up in the plot over the road sections without exit and access ramps.

Section 2 A27

Section 2 is located before the point where vehicles from the A2 join traffic on the A27. Three combinations were also made for these detection loops to determine the consistency of the loops: HMP 56.2 - 56.6, HMP 56.2 - 57.0 and HMP 56.6 - 57.0. First of all, it is noticeable that the detection loop 56.6 did not take any measurements in the year 2024. This shows that when using NDW data, the functioning of the loops should be checked, but it is not always possible to estimate in advance whether a loop has taken measurements. Therefore only the differences between detection loop HP 56.2 and 57.0 are measurable. These results are shown in Figure 67.

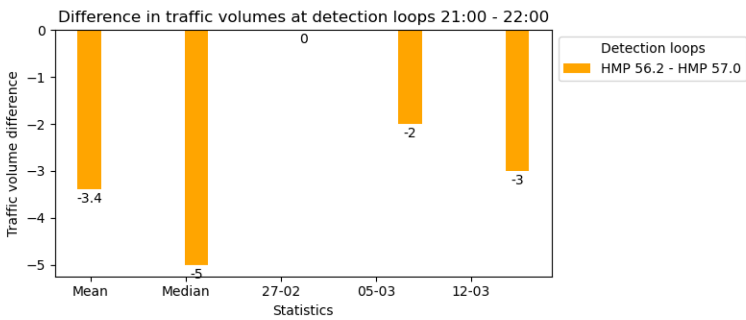

Figure 67: Difference in traffic volume in section 2 A27 between detection loops

Compared to the measurements in section 1, the measurements in 2024 are much smaller than those in section 2. This may be due to the fact that the detection loops in section 1 are located in a bend. In the bend, there is a greater chance that a vehicle will not completely pass over the detection loop. The differences between HMP 56.2 - 57.0 are small in 2024, and in this case, the loop HMP 56.2 detects only slightly more vehicles than 57.0. It can also be seen that the differences between 56.2 and 57.0 are small or even equal on the days of measurement.

Section 3-4 A27

Sections 3-4 contain the detection loops that come after the A2 and A27 merge to exit Hagestein. There are three loops that have been compared in the combinations: HMP 57.4 - 58.1, HMP 57.4 - 57.7 and HMP 57.7 - 58.1. The results are presented in Figure 68. In 2024, detection loop HMP 57.4 did not make any measurements and is therefore not included in the detection results of the first two loop combinations.

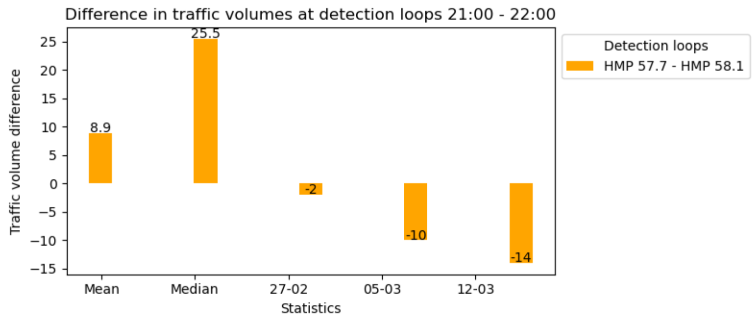

Figure 68: Difference in traffic volume in section 3-4 A27 between detection loops

The detection loop HMP 58.1 seems to detect more vehicles on the measurement days in 2024, but the statistical values are higher for the loop HMP 57.7. The results are tested for statistical significance in subsubsection 6.3.5, resulting in the detection loops not differing significantly from each other. Compared to the loop combination 56.2 - 57.0 in 2024, the difference in values for HMP 56.7 - 58.1 is slightly higher. This difference could be due to higher traffic volumes after the merging of the A2 and A27.

Section 4-5 A27

The loops tested for this hypothesis are the loops between the Hagenstein entry and the Nieuwegein exit. There are two loops, HMP 58.9 and HMP 124.4. The results for the differences between the two loops are shown in Figure 69. Loop HMP 58.9 gives a higher value for traffic than loop 124.4.

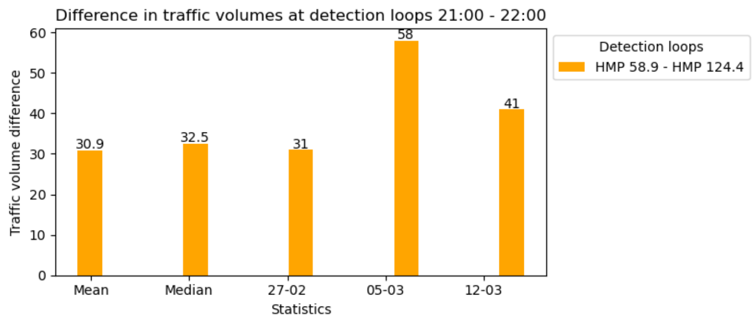

Figure 69: Difference in traffic volume in section 4-5 A27 between detection loops

Motorway A9 before exit Aalsmeer

For the A9 motorway, only one section is included that can be used to validate hypothesis 1. However, two different days, Tuesday and Thursday, were used for this section. Therefore for both days the differences in traffic volume between the detection loops HMP 30.8 and HMP 31.2 are considered. The results are shown in Figure 70. The results of the mean value show a difference between the considered days on which the detection loop shows more vehicles.

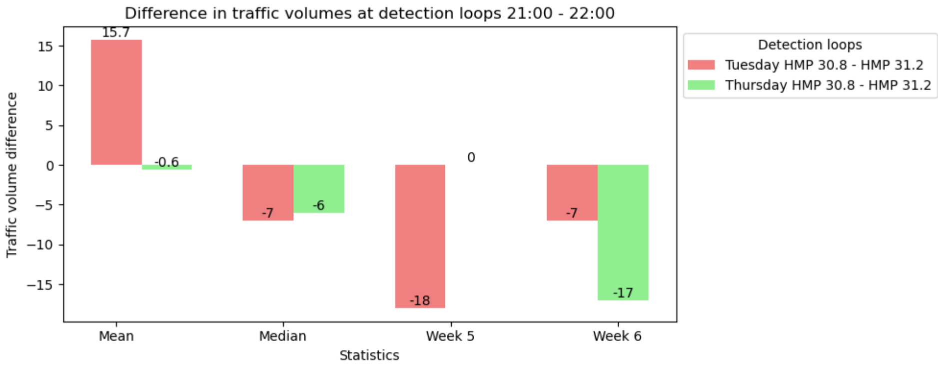

Figure 70: Difference between the detection loops A9

Statistical chi-square analysis Hypothesis 1
The linear regression method described in subsection 2.5 was used to determine whether the differences between the detection loop combinations were significantly different from each other. The chi-square independence test was used for this purpose, Equation 4. The differences between the detection loops are considered for the mean, median and days of measurement. The results of the statistical analysis are shown in Table 52. Despite the differences in values between the different detection loops, all calculated chi-square values are lower than the corresponding critical value, which is 3.84 for the individual differences and 9.48 for the sum of the chi-square values. The values of the different detection loops within a loop combination do not differ significantly from each other. In addition the overall significance

Table 52: Statistical chi-squared analysis results of hypothesis 1

21-22 2024	**Detection loop combinations χ^2**							
	HMP 74.1 - 74.5	**HMP 74.1 - 74.8**	**HMP 74.5 - 74.8**	**HMP 56.2 - 57.0**	**HMP 57.7 - 58.1**	**HMP 58.9 - 124.4**	**HMP 30.8 - 31.2 Tuesday A9**	**HMP 30.8 - 31.2 Thursday A9**
Mean	1.32	2.90	0.29	0.022	0.074	0.79	0.00087	0.13
Median	1.015	1.51	0.047	0.046	0.611	0.88	0.0095	0.44
Day 1	0.034	0.25	0.481	0	0.0085	0.78	0.014	1.08
Day 2	0.030	0.34	0.58	0.027	0.10	2.88	0.52	0.0028
Day 3	0.017	0.37	0.23	0.011	0.14	1.15		
$\sum\chi^2$	**2.42**	**5.40**	**1.64**	**0.10**	**0.94**	**6.50**	**0.55**	**1.66**

Pattern difference detection loops traffic volume
In the detection loops combinations that were considered for the first hypothesis, a correlation is found between the loops. The difference between two loop combinations is equal to the combination of the other two loops within a motorway section with three detection loops. For example, the A9 motorway detection loops HMP 30.8, HMP 31.2 and HMP 31.6 could be divided in three loop combinations: HMP 30.8 - HMP 31.2, HMP 30.8 - HMP 31.6, HMP 31.2 - HMP 31.6. These loop combinations and corresponding values are shown in Table 53.

Table 53: Correlation example detection loops

Detection loop combiantions	**Traffic volume difference**			
	Mean	**Median**	**Day 1**	**Day 2**
HMP 30.8 - HMP 31.2	13.3	25	-39	-2
HMP 30.8 - HMP 31.6	143.7	171	107	11
HMP 31.2 - HMP 31.6	130.4	146	146	13

The following correlation has been found between the combinations of these loops:

$$(\text{HMP } 30.8 - \text{HMP } 31.2) + (\text{HMP } 31.2 - \text{HMP } 31.6) = \text{HMP } 30.8 - \text{HMP } 31.6 \quad (6)$$

This correlation was also found for different loop combinations on the A27, shown in Table 54.

Table 54: Correlation example detection loops A27

Detection loop combiantions	Traffic volume difference			
	Mean	**Median**	**Day 1**	**Day 2**
HMP 74.1 - HMP 74.5	-26.2	-22.5	4	5
HMP 74.1 - HMP 74.8	-38.8	-27.5	-11	-17
HMP 74.5 - HMP 74.8	-12.6	-5	-15	-22
HMP 58.1 - HMP 58.4	63.7	54.5	70	70
HMP 58.1 - HMP 58.9	-147.5	-159.5	-171	-163
HMP 58.4 - HMP 58.9	-211.2	-214	-241	-233

This results in the following generic correlation between three consecutive detection loops:

$$(Loop1 - Loop2) + (Loop1 - Loop3) = (Loop2 - Loop3) \quad (7)$$

This correlation was unexpected because it was assumed that the loops were isolated from each other. Consequently, any measurement errors were expected to be independent. However, the loops measure the same traffic, leading to potential measurement errors for the same vehicles. Due to the lack of detailed information on how the measurements are taken and processed, the reasons for these measurement errors and their correlations cannot be definitively analysed in this study.

8.2 NDW intensity data versus ANPR cameras detections

In addition to the traffic volumes from the detection loops, on a number of days data was also available from the ANPR cameras, which counted the number of vehicles entering and exiting the slip road per hour. This section compares the number of vehicles detected by the ANPR cameras with the number of vehicles detected by the NDW data for two hypotheses. The second hypothesis suggests that the difference between the two detection loops before and after the exit represents the number of exiting vehicles. The same applies to the third hypothesis, but only for the access ramp. Here the difference in traffic volume between the loop before the access ramp and the loop after the ramp should be equal to the number of vehicles on the access ramp. Therefore, for both hypotheses, the number of vehicles on the exit and access ramps measured with the detection loops is tested against the measurements from the ANPR cameras.

Hypothesis 2

Three different exits were used in this study. The Hagestein exit is represented by the detection loops as the difference between HMP 58.1 and HMP 58.4. The Nieuwegein exit is the difference between HMP 58.9 and HMP 124.5. For the A9 case study, the difference is shown as the difference between HMP 31.2 and HMP 31.6.

Exit Hagestein

The ANPR camera which is installed at Exit Hagestein measured the number of vehicles on 27 February, and 5, 12 and 19 March. These measurements are compared with the number of vehicles which are measured with difference in the number of vehicles of the detection loops HMP 58.1 and HMP 58.4. For Tuesday March 19, there are no measurements available of the detection loops, and therefore excluded from the analysis. The results are shown in Figure 71.

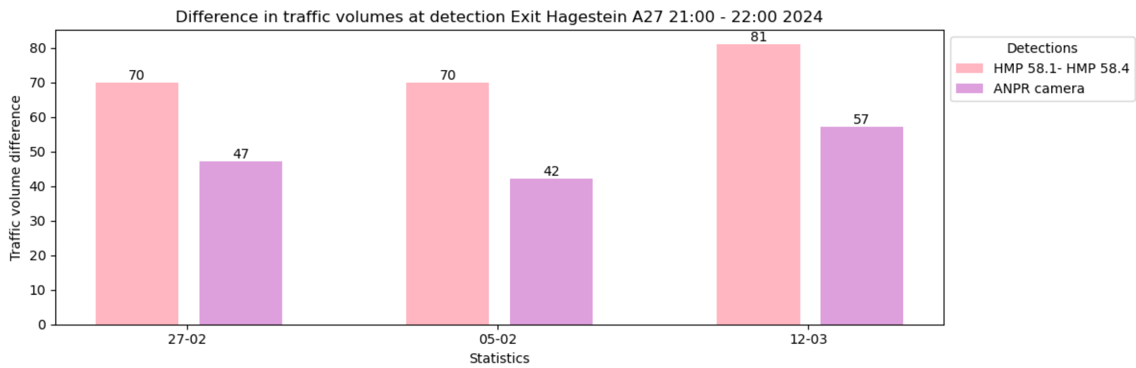

Figure 71: Difference between measurements Exit Hagestein

Exit Nieuwegein
For the exit at Nieuwegein, the detection loop before the exit, HMP 58.9 andthe loop after the exit HMP 124.9 is compared with the ANPR measurements, Figure 72. The results show that the detection loops suggest more vehicles at the exit than those detected by the ANPR cameras.

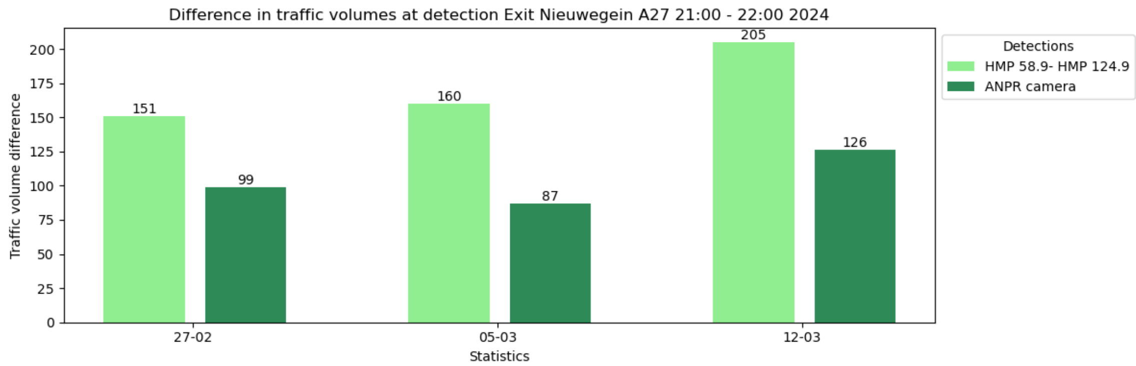

Figure 72: Difference between measurements Exit Nieuwegein

Exit Aalsmeer
For the A9 case study, the Aalsmeer exit is part of the analysis. The difference between the HMP 31.2 and HMP 31.6 detection loops was used to determine the numbers at the exit. For this case study, measurements were taken on two different days of the week. A second week of measurements is shown for both days. The numbers for the second Tuesday are lower than for the other measurements. This is due to a complete closure of the exit. The results of the comparison between the number of vehicles measured with the detection loops and ANPR cameras is shown in Figure 73.

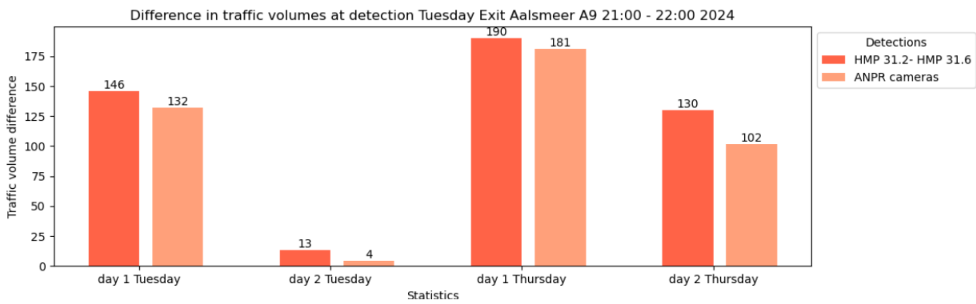

Figure 73: Difference between the detection loops Exit Aalsmeer

Statistical chi-squared analysis Hypothesis 2
To determine whether the differences between detection loops and ANPR cameras were significantly different from each other, the linear regression method described in subsection 2.5 was used. For this purpose, the chi-square independence test was used, Equation 4. The results are shown in Table 55. For exit Hagestein and exit Nieuwegein the chi-square value should not exceed the critical value of 5.991 and for exit Aalsmeer 3.841. The calculated chi-squared value for the differences in the detection loops and ANPR cameras exceeds the critical values and therefore the ANPR camera measurements and the detection loop measurements differ significantly from each other.

The measurements from the ANPR camera and the detection loops showed significant differences. These differences were unexpected as both methods monitor the same entry and exit ramps at the same time. However, the measurements were not taken at exactly the same locations, which could explain the variations. In addition, the variations between the detection loops suggest that there is an unknown factor influencing the results, which may be contributing to the differences between the two data sources. A more detailed discussion of the possible causes of these measurement variations can be found in subsection 9.4.

Table 55: Statistical chi-squared analysis hypothesis 2

21-22 2024	Hypothesis 2 χ^2			
	Exit Hagestein	**Exit Nieuwegein**	**Exit Aalsmeer Tuesday**	**Exit Aalsmeer Thursday**
Day 1	7.55	17.90	1.34	0.42
Day 2	11.2	48.05	6.23	6.03
Day 3	7.11	30.44		
$\sum\chi^2$	**25.86**	**96.40**	**7.57**	**6.45**

Hypothesis 3
The last hypothesis is tested using the same method as Hypothesis 2. The difference between the detection loops just before and just after the ramp should reflect the difference in the number of vehicles on the ramp and should not be significantly different from the measurements made with the ANPR cameras on these ramps.

Access Hagestein
For the Hagestein access slip road, the number of vehicles on the slip road was considered relative to the loop before the ramp and the loop after the ramp, HMP 58.4- 58.9. From the results presented in the Figure 74, it can be concluded that the loop combination HMP 58.4 and HMP 58.9 follows the largest number of vehicles entering the motorway from the access ramp.

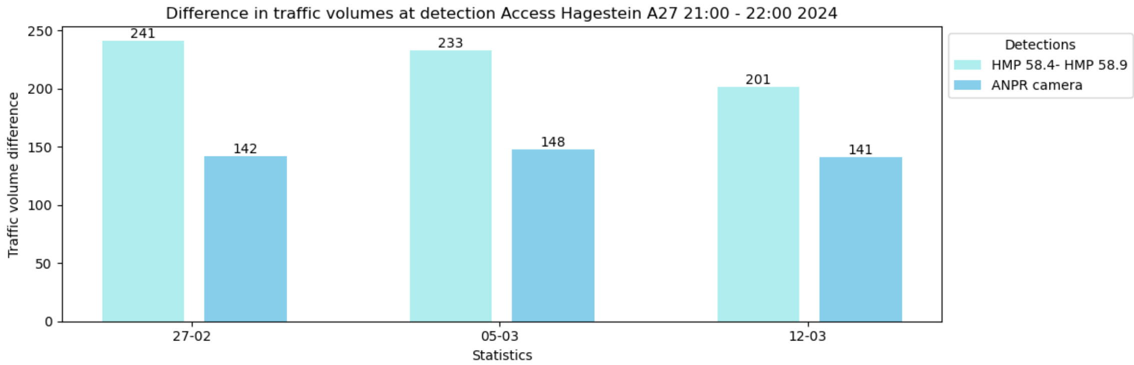

Figure 74: Difference between measurements Access Hagestein

Access Aalsmeer
The differences between detection loops HMP 31.6 and HMP 32.0 show the number of vehicles using the access road. These results are compared to the ANPR camera measurements shown in Figure 75. The number of vehicles measured by the detection loops is higher than that measured by the ANPR cameras.

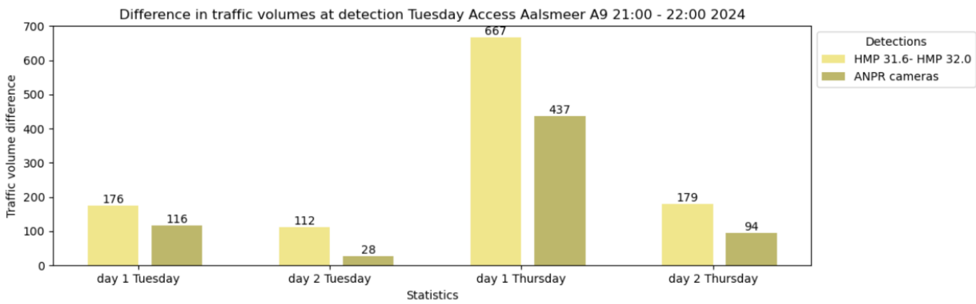

Figure 75: Difference between measurements Access Aalsmeer

Statistical chi-squared analysis Hypothesis 3
The differences between the measurements on the access roads were validated using the chi-squared test. The results are

shown in Table 56. All values found exceeded the critical chi-squared values, indicating that the different measurements were significantly different from each other.

Table 56: Statistical chi-squared analysis hypothesis 3

21-22 2024	**Hypothesis 3 χ^2**		
	Access Hagestein	**Access Aalsmeer Tuesday**	**Access Aalsmeer Thursday**
Day 1	40.66	20.45	79.31
Day 2	31.008	63	40.36
Day 3	17.91		
$\sum\chi^2$	**89.58**	**83.45**	**119.67**

8.3 Results Data Validation

By formulating and testing hypotheses, the consistency and accuracy of the data on different sections of the A27 and A9 motorways and the ANPR camera measurements were assessed. Focusing on the period between 21:00 and 22:00 in 2024 provided a concentrated dataset for in-depth investigation, chosen due to the high volume of traffic during this time. However, differences during other time periods are not assessed.

The validation process showed that while there are differences between the detection loops, these variations do not significantly affect the overall traffic measurements. This finding supports Hypothesis 1, which states that the variations in traffic volumes detected by the NDW loops are not significant. The analysis showed that the traffic volume measurements were consistent across the different sections of the motorway, despite minor differences between individual detection loops. However, significant differences were observed when comparing the number of vehicles on exit and entry ramps measured by NDW loops and ANPR cameras. Hypotheses 2 and 3, relating to the consistency of these measurements, were not fully validated. Statistical analysis confirmed that the differences between NDW loop and ANPR camera data were significant. This suggests that while both data sources are useful, they may capture different aspects of traffic flow and should therefore be interpreted with caution when used together.

The significant differences between NDW loop data and ANPR camera data highlight the need for careful consideration when integrating these two data sources for traffic analysis. These differences could be due to a number of factors, such as the positioning of the detection loops and the specific technology used by ANPR cameras. Therefore, it can be concluded that both methods can be used separately and can lead to the same insights, but exact numbers require further research on the differences in the data sources.

9 Discussion

This chapter provides a comprehensive discussion of the findings and implications of this research. The chapter starts with a reflection on the Detour Behaviour Model, followed by a discussion and interpretation of the results of the two case studies conducted. In subsection 9.3 the limitations of the research are examined. This is followed by a reflection on the data. In addition, the results are discussed in terms of their generalisability and comparison with existing literature. Finally, the implications of the findings for practice are explored.

9.1 Detour Behaviour Model Reflection

The conceptual model framework, created to analyse the behaviour of road users around motorway diversions was mainly based on existing literature and the brainstorming session. The Detour Behaviour Model consists of several components: the Detour Decision Process, the Detour Behaviour Factor, and Driving Styles, from which driver profiles and driving patterns around detours are derived. The designed model was then presented to the same participants from the brainstorming session in order to validate the model. Despite the validation by the brainstorming participants and the evaluation of the model against the case studies, several components of the model were not tested further.

The decision process consists of the main choices the driver has to make regarding detours. These decisions are based on the event of following or not following a detour and possible situations that may arise as a follow-up of this decision. It does not include why the driver makes a decision and the reasons behind it. Additionally, the model does not consider other available routes around a closure. For example, while choosing another route might influence the main choices, this depends on the location of the closure. It is also beyond the scope of this study to determine whether a driver is familiar with other routes around the detour or to track the driver's final destination accurately. This makes it challenging to fully understand the decision to take an alternative route.

The research examined the wide range of factors that influence driver choice and grouped them into three distinct categories: psychosocial, contextual and economic. Although these factors have been identified, their individual impact on detour decisions has not been fully explored. In addition, potential correlations between these factors could affect the evaluation of the study. To address this, the expertise of participants in a brainstorming session was used to develop strategies for measuring contextual and economic factors in the case studies. By analysing the differences observed in the two case studies, the research identified possible links between different conditions and detour behaviour. This approach allowed an assessment of the potential impact of these factors on the case study results.

The model developed included four types of driver profiles relevant to detours, based on a synthesis of potential factors, decision-making processes and different driving styles. From the literature review and brainstorming session, these driving styles were identified and redefined in terms of their association with detours. While it was not possible to investigate driving styles per vehicle in terms of speed changes due to measurement limitations, and the lack of individual driver identification limited a comprehensive understanding of the factors influencing these profiles, the route choice analyses still allowed the identification of driver profiles around detours based on the route chosen.

Finally, the model also includes scenarios that could occur around a closure. The evaluation of the model with the case study results showed that not all of the derived driving behaviour scenarios were found. The scenarios were tested with one type of closure, leaving open the possibility of different results with alternative types of road closure, such as motorway closures. Moreover, analysing time periods shorter than one hour might reveal more driving patterns.

Overall, the Detour Behaviour Model provides a structured framework for evaluating the complex dynamics surrounding detours and road closures. While observational studies can be conducted without the model, it provide more information into route choice and road user behaviour by identifying and understanding four distinct driver profiles and their decisions in response to detours. Case study evaluations have demonstrated the effectiveness of the model in understanding different scenarios during road closures. However, to gain a more detailed understanding of the specific relationships between different factors and drivers' route decisions, the model requires further investigation.

9.2 Results Interpretation

This research, using two case studies, provides an overview of road users' route choices around a road closure on the secondary network immediately after the motorway exit ramp, and examines the impact of associated temporary traffic measures. The results are interpreted in terms of route choice and motorway speed adjustments.

Route decisions

The analysis of the A9 and A27 case studies shows differences in the route choices made by drivers encountering road closures. In the A9 case study, route choice is primarily determined by whether vehicles pass the exit in the direction of the closed road. In contrast, the A27 study offers a more detailed examination of the different route options available to drivers, providing a more nuanced understanding of route choices. While the A9 case study reported a compliance rate between 28.2% and 81.7% with diversion signs, the limited route analysis may introduce bias. Vehicles that bypass the exit are classified as following the diversion, but their final destinations and exact routes remain uncertain. Some vehicles may use alternative routes not captured in the analysis, affecting the accuracy of diversion compliance scores. However, it identified a significant non-compliance towards the traffic signs. The number of vehicles taking the exit to the closed road and having to turn back towards the motorway shows a significant number of non-compliant rates between 18.3% and 73.8%. This range is determined by comparing the number of vehicles that turned at the roundabout due to the closure of the Schipholweg with the expected number of vehicles on the exit ramp (18.3%) and further specifying the number of vehicles from this group that were expected to head towards the Schipholweg (73.8%). Therefore, it can be said that 73.8% of the road users heading towards Schipholweg do not follow the diversion signs during the closure phase, which is 18.3% of the expected traffic on the exit ramp.

The A27 case study provides a more detailed understanding of the routes taken by drivers due to the road closure by analysing pre-defined possible routes. Although other potential routes may not have been considered, the case study still benefits from a detailed understanding of the traffic flow around the closed road. This allows a more accurate estimation of expected vehicle volumes at different times, although uncertainties remain about the original routes and final destinations of vehicles. In the A27 case study, the presence of an alternative route after the exit makes it more challenging to determine whether vehicles taking the exit did not consider or see the temporary signs. It is possible that drivers familiar with the environment made a considered decision to take the exit and use the appropriate alternative route. In the case of the A9, where there was no route option after the exit, drivers may have taken the exit on the assumption that they could find an alternative route. More information about the drivers would be needed to gain a more detailed perspective.

In both studies, the percentages of route choices are based on expected and measured vehicle numbers. Expected vehicle numbers, determined by linear regression, help to estimate normal conditions. However, the undefined distribution between work, local and occasional traffic makes it difficult to accurately estimate the number of diverted vehicles. If the detected vehicles exceed expectations, the proportions are based on observed numbers; otherwise, they are based on expected values, which could introduce bias. This approach is derived from the developed diversion behaviour model, which takes into account vehicles that avoid the closed road. To identify this group, the difference between detected and expected vehicles is used as the proportion of this group. The distribution of vehicles taking different routes is based on the detection locations of the ANPR cameras. Therefore, the A27 case study includes the following route information: Vehicles detected on the Nieuwegein entry and exit ramps (Route 1) are assumed to be following the diversion; Route 2, using the diversion, shows the proportion of vehicles using the Hagestein exit towards Lange Dreef, which are assumed to be normal users of the closed road; Route 3, returning to the diversion, shows vehicles that initially took the Hagestein exit but then followed the correct diversion route after encountering the closure.

The case study data can be used to estimate the number of vehicles that did not follow or did not notice the diversion information. For the A27 case study, the proportion following the detour is equal to the number of vehicles detected on Route 2. For the A9 case study, of the vehicles that continued on the motorway, it can be concluded that they noticed the signs, although they may have taken different decisions after seeing them. The vehicles that did not see the signs or intentionally did not follow them are, in the case of the A9, the vehicles that returned to the motorway after taking the exit. For the A27, these are the vehicles that returned to the motorway after taking the Hagestein exit in order to use the Nieuwegein exit and access to Nieuwegein, Route 3. It can therefore be assumed that at least 4% did not see or follow the signs at all for the A27 case study and 18.3% for the A9 case study. The lower percentage on the A27 is due to the availability of the shortcut after the exit ramp, which is followed by 60% of the vehicles. This gives a total of 64% of non-compliant vehicles. In addition, it is reasonable to assume that the actual rates of failure to follow signs are higher in both cases. For the A27 this is indicated by the fact that the percentage of vehicles following signs is 33% and for the A9 the route taken by vehicles after the exit was not analysed.

Combining the results from the two case studies gives a range of 18.3% to 73.8% of vehicles not obeying diversion signs. A detailed analysis of route choice from the A27 case study shows a 64% non-compliance rate during the closure phase, which falls within this range. However, a comparison of the two case studies suggests that the 18.3% rate is a very low estimate. A more accurate indication of the expected number of vehicles on the closed road suggests a narrower range of non-compliance. Therefore, by focusing on this expected number of vehicles for the closed road and vehicles not following diversion signs, the range of non-compliance can be refined to 64% to 73.8%.

Motorway behaviour
As it is not possible to determine the average speed dynamics of individual vehicles with the data available in this study, the effect of the temporary traffic measures on the motorway can only be assessed in terms of the overall traffic flow. As the closure is on the secondary road network, it does not affect all traffic and there may be more impact from temporary traffic measures than can be measured by the average speed on the motorway. The data available included the volume of traffic on the motorway and the average speed. Using these data, no significant changes in behaviour around the signs were observed. In the A9 case study, speed changes were observed. However, additional measures such as a lane closure and a lower speed limit were also in place around the exit. It is therefore difficult to determine whether the speed change was directly due to the information provided by the temporary signs or the result of these additional measures. Despite these limitations, the observations still provide valuable insights into overall traffic patterns and the potential influence of temporary traffic measures on the total traffic volumes on the motorway.

9.3 Limitations of the research

By selecting two case studies for an observation study, this research aimed to provide valuable insights. However, it is important to recognise and address certain limitations associated with this study that are not already discussed in the interpretation of the results.

Firstly, the closures in both case studies were on secondary networks, limiting the understanding of driver behaviour in response to alternative closures. In addition, the study period was limited to specific nights in February and March 2024, which may not accurately represent typical traffic patterns throughout the year. Seasonal variations or specific events during these nights could influence the results. In addition, the data available for analysis may have been limited to a shorter time period, limiting the ability to identify and understand long-term trends in road closure and diversion behaviour. Fluctuations in traffic volumes due to incidents, congestion or special events were not fully investigated, which may limit the full understanding of motorway dynamics. While there was considerable variation in the number of vehicles detected per hour, particularly during low-traffic periods such as night time, this variation could enrich the robustness of the results by highlighting different traffic conditions.

Observations of route choice during closure periods indicate that a significant proportion of vehicles do not follow detour signs. However, when interpreting these patterns, factors such as familiarity with alternative routes, perceived inconvenience of the diversion and real-time traffic conditions should be considered when influencing driver decision-making. The lack of a clear trend in average speeds around signs and exits across different phases and time periods suggests that factors other than closure measures may influence driver behaviour and the effectiveness of traffic signs. In addition, for the A9 case study, it was not possible to determine how traffic reacts in terms of total average speed to the signs due to the traffic measures applied in the same section. Furthermore, the absence of measurement on the closed roads (Hagenweg, Schipholweg), particularly during the pre-and post-closure period when the road was (re-)opened but traffic signs were in place, limits the ability to fully investigate traffic behaviour during this transitional period. In addition, a better indication of the vehicles expected at different times could be obtained by taking measurements during business-as-usual periods on both roads.

It is important to recognise the influence of non-quantifiable factors such as navigation systems on route choice behaviour and compliance with diversion signs. Navigation systems play a valuable role in guiding drivers during road closures, but their impact on route choice and compliance is difficult to measure. This study does not take into account whether drivers were using navigation systems, their activation status, or compliance with suggested routes. In addition, navigation systems allow for dynamic route adjustments based on real-time traffic conditions, which may deviate from predetermined detour routes indicated by signage. While these effects cannot be directly measured in this research, they remain important considerations in understanding and interpreting observed route choice and compliance behaviour during road closures.

9.4 Data reflection

The study uses data derived from NDW data and measurements from ANPR cameras. The use of detection loops and NDW data in traffic behaviour analysis provides valuable information about traffic flows and vehicle behaviour on motorways. The use of ANPR cameras to assess the effectiveness of traffic diversion signs provides valuable insights into driver behaviour and route preferences. However, it is important to be aware of the various factors that can affect the accuracy and reliability of these measurements.

9.4.1 NDW data

Despite the widespread use of detection loops for traffic monitoring, there are certain limitations that need to be considered when interpreting the data obtained. One of the possible explanations for variations between detection loops is that vehicle axles do not fully cross the detection loop, resulting in underestimation or missed detections. In addition, lane-changing behaviour of vehicles at the location of a detection loop can result in vehicles being either missed or counted multiple times. In addition, there can be variations in detection times between loops, particularly during the transition between hours, which can lead to data inconsistencies. Furthermore, multi-axle vehicles or those with trailers may not be consistently detected by different loops, leading to inconsistencies in the recorded data. Some of the detection loops located on Dutch motorways are capable of classifying vehicles into different classes, the loops considered in this study do not have such capabilities, limiting the depth of knowledge about the observed differences between detection loops.

Similarly, when relying on NDW data, it is important to recognise the limitations and potential sources of error associated with this approach. The use of detection loops for traffic counting is subject to a number of factors, including the shape of the loop and the speed of passing vehicles. In addition, inaccuracies in processing algorithms and modelling assumptions can lead to inconsistencies between the recorded data and actual traffic conditions. The differences in data quality between the NDW data and the original situation can be seen by comparing the numbers obtained from the detection loops and the ANPR cameras. As a result of the data validation in section 8, the differences between the data from the NDW and ANPR cameras are significantly different. This indicates that the reliability of the traffic volumes from the NDW data is limited.

9.4.2 ANPR cameras

Firstly, the ANPR cameras used in the study recorded the passage of vehicles at specific locations, making it possible to identify number plates and determine whether a vehicle had passed through several checkpoints in a given period of time. However, the recognition of vehicles is limited to the locations of the ANPR cameras. Therefore, the routes that can be determined may not include all possible route options available to drivers. Furthermore, in this study, only the predefined routes are taken into account in the analysis of route selection. Alternative routes and deviations from expected routes were not systematically considered. This limitation suggests the necessity of a detailed understanding of the driving environment and the various factors influencing route choice.

There are also a number of factors to consider when interpreting the data from these cameras. A common challenge with ANPR cameras is the occurrence of double scans, where vehicles are recorded multiple times due to long periods of stationary or slow-moving traffic. In addition, the accuracy of ANPR number plate recognition is not guaranteed. Variations in lighting conditions, the presence of dirt on number plates or even bad weather can cause inconsistencies between recorded and actual number plates. Another reason for differences in detection is the fact that for the A9 case study, the first location measured the front number plate of the vehicle and the access ramp camera measured the rear number plate of the vehicle, which can contribute to inconsistencies in data collection and potentially lead to misinterpretation of the driver's route choice. Furthermore, the cameras can detect text written on the vehicles as licence plates. However, it is possible to filter out this wrongly detected text from the data during the processing of the data. An additional consideration relates to the interpretation of route choices observed through ANPR data. The imposition of a strict timeframe for route matching, typically within a certain period in minutes between successive camera scans, may overlook certain route variations or detours taken by drivers. Adjustments to matching windows or criteria may be required to provide a more comprehensive picture of driver behaviour and route preferences.

9.5 Generalisation of Results

This research has provided a comprehensive conceptual framework for understanding the behaviour related to road closures and associated detours. The resulting detour behaviour model has the potential for broader application beyond the specific scenarios analysed in this study.

The framework presented in Figure 18 is developed from considerations of a full road closure within the secondary road network adjacent to a motorway exit. However, its principles are adaptable to various other types of road closures, as discussed in subsection 4.6. The model is based on the assumption that road closure information is presented along the motorway, but is not limited to one location. This assumption allows the model to be useful for traffic managers in anticipating and managing the various situations that can arise in relation to road closures and the diversion of vehicles travelling from the motorway.

In addition, two case studies were analysed, looking at traffic flows on the motorway and the route choices made based on the information displayed on the temporary traffic signs. The findings show that during road closures, a significant proportion of vehicles do not follow the diversion signs but choose to continue in the direction of the closed road. This behaviour appears to depend on the availability of alternative routes, but also on other factors such as traffic congestion, time of day and individual driving preferences. Factors such as the availability of alternative routes, familiarity with the area, travel time and distance to destination are likely to play a role in drivers' decision whether or not to follow diverted routes.

While both case studies focus on access road closures within the secondary network, differing in terms of the availability of alternative detours after exiting the motorway. The results show a baseline of 18.3% of traffic not complying with motorway detours during closures, with this number increasing to an average of 65 - 73.8% throughout the closure period when alternative routes are available. The study therefore shows that, in general, when considering compliance with temporary traffic measures for road closures on the secondary road network, there is an identifiable number of drivers who do not comply with these measures.

9.6 Comparison Results with Literature

This study provides knowledge on compliance with static diversion signs during road closures, whereas the literature mainly focuses on the effectiveness of dynamic route information systems such as variable message signs (VMS). Although there are limited directly comparable studies, some comparisons can be made with findings from previous studies. Some of the previously conducted studies considered examine diversion compliance of VMS in different situations.

Chatterjee and Mcdonald [17] investigated drivers' responses to VMS in urban areas. The VMS provided route guidance to improve the efficiency of the road network and as a result, they found an overall compliance rate of 92% to the information. This compliance rate is significantly higher than the rate found towards detour information in this study. Other studies identified lower compliance ratios. Horowitz, Weisser, and Notbohm [52] found that during peak periods alternative-route selection based on estimated travel times to motorway traffic is equal to rates of 7-10% varying by location and day of the week. However these observations were conducted around work zones on the motorway, the road was not completely closed. Therefore this compliance rate equals vehicles who chooses another route because of the potential delay around the work zone. Erke, Sagberg, and Hagman [38] investigated the impact of route guidance VMS on speed and route choice on motorways, resulting in higher proportion of vehicles of approximately 20% changing their route. Davidsson and Taylor [26] examined VMS which suggested alternative routes to avoid congestion, with 6-41% driver response rates. Additionally, Ramsay and Luk [102] shows that announcing a road closure increases the number of vehicles diverted by 30%. The A9 case study shows a minimum compliance rate with the measures of 26.2%. In the case study of the A27 of the Hagenweg closure, an overall compliance rate to the indicated detour showed a similar proportion of diverting vehicles of 32%. This percentage is higher than the previous values found, but this is based on the road being closed and the previous percentages were based on vehicles taking a detour when the road remains open.

Desai et al. [29] analysed diversion patterns associated with unplanned road closures on major motorways. By examination of 12 case studies, they found that choosing another route rather than staying on the base route is in the range of 58% to 93% for road closures exceeding five hours. However, the A9 case study shows the proportions of a planned closure. The A27 case study is not able to cover these figures. However, the range of alternative route choices obtained from the A9 case study can be determined. The percentage of people choosing an alternative route instead of trying to use the intended route showed an overall range from 26.2% to 73.8%. This range is wider and has a lower maximum value than the range found in Desai et al. [29], but the maximum value is within the range found.

Although compliance with static diversion signs is not as well known as for dynamic systems, comparative studies suggest that the effectiveness of diversion measures depends largely on the clarity and relevance of the information provided. Previous studies have shown that displaying relevant information, such as delay times or alternative routes, can significantly increase drivers' willingness to follow diversions. For example, Reinolsmann et al. [103] showed that indicating the total travel time on a GRIP instead of VMS the percentage of drivers taking an alternative route increases from 36.25% to 61.25%. The percentage of drivers taking the alternative route was doubled to 73.75% when delay times were displayed on the VMS. In addition, the percentage of drivers taking the alternative route increased from 61.25% to 81.25% if the delay time was shown on the GRIP. These compliance rates are higher than the values found in this study. This shows that there is a difference in effectiveness between static road signs and VMS.

9.7 Results Implication

The analysis of the ANPR camera data shows that a significant proportion of vehicles do not comply with temporary traffic measures by using the exit ramp despite the road closure immediately after the exit. This non-compliance indicates the need for adjustments in traffic management strategies. In addition, it is important to consider the safety risks, including collision risk, faced by the workers responsible for installing signs along the motorway. Given the low compliance level of these traffic signs, the need to evaluate their placement and explore alternative approaches becomes a major consideration.

The dynamic characteristics of traffic behaviour around road closures emphasise the need for adaptive traffic management strategies capable of responding to changing conditions and efficiently recommending detour routes. Findings from the existing literature on diversion rates using variable message signs and real-time traffic data suggest promising opportunities for improvement. Improvements in traffic management practices, such as real-time traffic updates and proactive communication with road users, have the potential to facilitate better management of road closures and improved traffic flow. The increasing use of navigation systems, such as TomTom and Google Maps, provides an opportunity to improve traffic re-routing around closures by incorporating drivers' personal preferences into the decision-making process.

10 Conclusion and Recommendations

This research addresses the gap in understanding the effectiveness of static traffic signs around road closures. By developing a detour behaviour model and conducting two observation studies, this study aims to answer the main research question::

What is the influence of static traffic signs on motorways on drivers' route choices and driving behaviour on following a detour?

To address the main research question in a systematic way and to identify drivers' route choices and driving behaviour to static traffic signs around work zones and associated detours, a series of sub-questions were developed. The first sub-question focuses on providing a theoretical framework to demonstrate road users' responses to detours. The other two sub-questions guide the investigation of driver behaviour around motorway detours and the extent to which road users follow static traffic signs.

In this chapter the findings of the research are discussed. First, the conclusions of the research are presented, addressing the main research question and objectives. In addition, the scientific contributions of this study are outlined and directions for future research are suggested. Finally, the practical implications and recommendations are discussed.

10.1 Conclusion

Through two observation case studies investigating route choice and driving behaviour in response to road closures and static traffic signs, this study advances the understanding of route choices and driving behaviour of road users around detours, and the corresponding impact of static detour traffic signs. This research not only provides insight into the complex interaction between static control measures and road user decision-making but also provides a systematic conceptual framework for understanding road user detour behaviour.

The study identified four main decisions that drivers make in response to an announced detour: follow the detour, take a different route, avoid the location during the closure, or ignore the closed road. These decisions were grouped into four driver profiles representing the range of choices around a detour influenced by factors that are divided into three categories: psychosocial, contextual and economic. These factors influence not only the choices made by the driver but also the driving style on the motorway and around the closure.

Two case studies involving access road closures on the secondary road network provided an empirical insight into drivers' actual decisions. The results showed that a significant proportion of drivers, ranging from 64% to 73.8% over the total closure phase, decided not to follow the detour signs. Instead, they either continued on their original route and attempted to head towards the closed road despite the signage, or changes from route taking an available shortcut. This indicates that the impact of temporary signs on a significant proportion of motorway drivers is limited.

The results of the study show that the four different driver profiles and their corresponding detour route choices are indeed observed in real-world scenarios. Driver Profile 1, which is characterised by a willingness to follow the detour, accounts for a proportion of between 26.2% and 36%. Meanwhile, Driver Profile 2 is characterised by not following the detour, which accounts for a proportion of between 64% to 73.8%. While, this profile interacts with Driver Profile 3, where drivers choose alternative routes, such as shortcuts. In the case study of the A27, around 60% of drivers chose this available shortcut option. In addition, Driver Profile 4 represents a minor contribution of 4%, consisting of drivers who follow the information by avoiding the closed road.

These results emphasise the complexity of driver behaviour around road closures and demonstrate the limitations of temporary road signs in influencing a significant proportion of drivers. In combination with the lack of significant deviations in the speed of drivers on the motorway around the signs, this further supports the limited influence on the driving behaviour of road users. Therefore, it can be concluded that the detour signage on the motorway does not influence between 64% and 73.8% of road users in their decision to follow a detour due to a road closure. Therefore, the study concluded that a significant number of vehicles do not comply with temporary traffic measures, including static detour signage.

This research was motivated by several accidents involving road workers installing diversion signs, highlighting the urgent need to improve the safety of these workers. Given the low compliance with static diversion signs and the high risks associated with their placement, it is recommended to explore and implement alternative methods of traffic control. This could include the use of dynamic, real-time information, such as smart traffic systems and mobile applications, to guide road users more effectively and improve the safety of road workers. By focusing on road user route choice through the Detour Behaviour Model, proactive measures can be developed, ensuring that traffic management strategies are more closely aligned with actual route choices.

10.2 Scientific contribution

The scientific contribution of this research lies in the comprehensive investigation of driver decision-making and driving behaviour in response to static traffic signs during road works and detours. By addressing research gaps in understanding the effectiveness of temporary static traffic signs rather than the effect of variable message signs. Using two case studies, the research provides insights into the complex dynamics of road user behaviour and decision-making in real-world environments.

Firstly, the research contributes to a deeper understanding of road users' decision-making processes by identifying four main decisions drivers can choose from when faced with a detour announcement. These decisions, ranging from following the detour to ignoring the closed road, provide a framework for analysing driver behaviour in detour situations. The categorization of the four main decisions in driver profiles provides a nuanced understanding of the diversity of responses among road users. This classification provides valuable insights into the factors that influence drivers' choices and driving behaviour, including psychosocial, contextual and economic factors. In addition, the empirical findings from the case studies provide real-world validation of the identified driver profiles and decision-making patterns. The observed proportions of drivers within each profile emphasise the extent of different responses to detour instructions and indicate the limitations of temporary static traffic signs in influencing driver behaviour.

This study developed the Detour Behaviour Model to provide a structured understanding of drivers' responses to detour instructions and their decision-making processes. This model makes a valuable contribution to the literature by providing a systematic framework that captures the complex dynamics involved in detour scenarios and the multiple factors that influence related decisions. By addressing these complexities, the Detour Behaviour Model not only improves the understanding of detour behaviour but also provides a solid foundation for future research efforts in the area of detours and road closures.

Furthermore, this study addresses a gap in the literature by focusing specifically on the influence of static temporary traffic control measures placed around work zones. While previous research has focused on the effects of variable and dynamic message signs (VMS), the role of static signs in guiding driver behaviour has been relatively unexplored. By focusing on this aspect, the research provides new knowledge about the effectiveness and influence of static traffic signs in shaping drivers' decisions on the road. Additionally, this study applies observations, a methodological approach not commonly used in the existing literature on traffic control measures. In contrast to the simulation studies that are common in previous research, observations provide an empirical understanding of drivers' decision-making processes in real-world scenarios. By applying this approach, the research contributes to the development of empirical knowledge in this area and provides robust findings about the complex dynamics of road user behaviour.

10.3 Future research

This study provides valuable insights into road user behaviour during road closures, diversions and the effectiveness of temporary traffic control measures. However, further research is needed to address the limitations of the current study and to fill relevant research gaps. Recommendations for future research focus on two main topics: detour behaviour and traffic control measures.

This study has developed a detour behaviour model that captures the complex dynamics between detour behaviour and decision-making. Future research is recommended to improve and extend the applicability of this framework, particularly in the context of road closures and detours. Evaluating the effectiveness of the model beyond full closures on secondary road networks, and adapting it to urban settings, can enhance its validation and robustness. Additionally, improving the developed model requires a deeper understanding of the decision-making processes. Further evaluation of the identified factors influencing decision-making and driving behaviour, and investigation of their correlations and interactions, will further improve the understanding of driving patterns around road closures. In addition, driver profiles and driving styles can be further defined by investigating the associated factors. The use of qualitative methods such as surveys and interviews can reveal drivers' motivations, perceptions, preferences and attitudes towards detour signage and route choice, and contribute to the development of a more comprehensive model of detour behaviour.

Future studies could observe how driver behaviour evolves in response to static traffic signs and diversions under different circumstances, such as differences in the duration of road closures, the time of day of road closures or possible seasonal influences, providing valuable insights into trends and factors influencing changes in behaviour. In addition, examining the impact of temporary traffic measures on motorway behaviour, including changes in average speeds, traffic volumes and lane occupation patterns, can identify areas for improvement in diversion management strategies and a better understanding of driving behaviour.

Moreover, given the identified risks associated with the installation of traffic signs along motorways and the observed low levels of compliance with temporary traffic measures, future research could investigate the safety implications of non-compliance for both road users and workers responsible for installing signs along motorways. This could include conducting risk assessments and evaluating the effectiveness of safety measures such as temporary barriers, warning systems or automated flagging devices in mitigating the associated risks. Such studies could lead to the development of improved protocols and equipment to improve worker safety.

Future research into the effectiveness of different traffic management strategies has the potential to improve the efficiency and safety of road closures. Conducting controlled experiments or observational studies in different roadworks environments to investigate optimal sign configurations and communication strategies, and evaluating the impact of public awareness campaigns, can improve the understanding of the effective provision of detour information and compliance rates. Exploring the implications and possibilities of navigation systems is another interesting area for future research. In-car navigation systems can provide real-time information to the road user according to the driver's preferences. Investigating how drivers use guidance systems to influence route choice and their potential to override traditional signage could lead to new traffic management strategies. In addition, the impact of navigation systems on the attention of the road user to traffic signs and the road situation enhances the knowledge of factors influencing driving behaviour.

Finally, investigating the effectiveness and compliance of road diversions and closures in urban areas is an interesting topic to add to current knowledge. Both urban and rural roads are frequently subject to maintenance works that require closures and detours, making it essential to investigate the impact of such measures. Understanding how traffic signs and route choices influence drivers provides valuable insights into the motivations for following or avoiding detours and the differences in this type of environment compared to motorway signage. By conducting research in different environments and comparing management strategies and their effectiveness in different scenarios, a deeper understanding of driver behaviour and decision-making processes can be gained. This comprehensive approach enables the design of more effective traffic management strategies, adapted to the specific needs and behaviour of road users in different contexts.

10.4 Practical contribution and recommendations

The results of this research have major practical implications for increasing the safety of road workers and improving traffic management during roadworks and diversions. By revealing the complexity of drivers' decision-making processes and their behaviour towards static traffic signs, this study provides valuable information that can be used to develop more effective traffic control measures.

Firstly, the identification of four main decisions made by drivers in response to detour announcements provides information about the responses that occur on the road. Understanding these decision patterns can assist authorities in designing targeted interventions to better manage traffic flow and ensure the safety of both road users and workers in work zones. In addition, the empirical findings from the two conducted case studies indicate the need for improved signage strategies and communication methods to effectively guide drivers during road closures. The significant proportion of drivers who do not follow detour signs emphasises the importance of the changes required in traffic control management strategies.

The high risks faced by road workers when installing traffic signs, combined with low compliance by motorists, highlights the need to re-evaluate the placement and effectiveness of these signs. For example, in the A27 study, only 33% of road users followed diversion signs, despite the installation of 14 signs in this area. This widespread non-compliance exposes road workers to risk in a number of locations and raises significant safety concerns. The lack of traffic complications for those who chose to drive towards the closed road and take a shortcut further indicates the need to reconsider current sign placement and traffic measures. Furthermore, the collision risks faced by road workers installing static signs must be addressed. Given the low impact of static signs and the high risks associated with their placement, it is recommended to explore and implement alternative methods of traffic control, by potentially reducing the number of static signs and implementing additional safety an traffic control measures, road workers' risks can be reduced and overall traffic management around work zones can be improved. Other traffic control measures could include the use of dynamic, real-time information, such as smart traffic systems and mobile applications, to guide road users more effectively and improve the safety of road workers.

In this study, it was not possible to determine the influence of navigation systems on the choice of routes driven. However, it is apparent from the literature that navigation systems are widely used. This makes it very useful for practical implications to investigate in which manner navigation systems can support making road works safer. By providing additional support in the notification of road works in the navigation systems and by linking the correct diversion routes in the systems, it can be investigated whether the follow-up of the measures can be increased.

The results of this study contribute to the understanding of the impact of road closures on traffic patterns. It also indicates the importance of re-examining traffic management strategies and consideration of fewer or strategically different sign locations. By using these findings, authorities can move towards a more effective and efficient approach to directing motorists, while reducing risks to road workers, thereby promoting a safer road environment for all.

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Effectiveness of static detour signage on motorways

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Several incidents involving the installation of temporary traffic signs by road workers have raised concerns about the effectiveness of these signs. Even in the absence of incidents, effectiveness is a relevant question, made more urgent by the incidents and the high risk of collision faced by road workers installing the signs. This paper investigated the influence of static traffic diversion signs on drivers' route choice and driving behaviour during road closures on secondary roads adjacent to motorways in the Netherlands. The influence of static diversion signs is assessed by analysing route choice, detour compliance and changes in driving behaviour, in terms of speed variations around diversion signs. In addition, the paper aimed to develop a detour behaviour model that classifies drivers into four different detour driver profiles. These profiles are developed based on potential route choices, driving patterns around road closures, detour behaviour factors and driving styles. Therefore, the four driver profiles are categorised as following the detour, not following the detour, choosing an alternative route and avoiding the closure area. This model provided a systematic framework for understanding detour route choices and shows the complexity of driver behaviour around road closures. Two case studies are evaluated by an observation study on route choice, detour compliance and speed adjustments around detour signs, during night-time road closures. The first case study was conducted near exit 9 Aalsmeer on the A9 motorway and the second near exit 27 Hagestein on the A27 motorway in the Netherlands. Observations from the A9 case study showed that 73.8% of the road users heading towards the closed road do not comply with the detour signs during the closure phase, which accounts for 18.3% of the expected traffic on the exit ramp. A more detailed analysis of route choice in the A27 case study showed a 33% compliance rate with the detour. A significant proportion of road users (60%) showed non-compliance by disregarding signs and taking the shortcut. In addition, a small percentage (4%) did not initially follow the diversion but later returned to the motorway to comply, while a further 4% chose to avoid the closed road area altogether. Therefore, the non-compliance rate across both case studies ranges from 64% to 73.8%. The results showed that static signs have a limited effect on diverting traffic to the detour. Moreover, there are no significant changes in speed around the signs found, supporting a limited effect on changing driver behaviour. The paper highlights the complexity of driver behaviour around road closures and demonstrates the limited effectiveness of static diversion signs in directing traffic to detours. These findings emphasised the importance of re-evaluating sign placement and it is recommended to explore and implement alternative methods of traffic control. This could include the use of dynamic, real-time information, such as smart traffic systems and mobile applications, to guide road users more effectively and improve the safety of road workers. Future research should focus on individual-level road user and factor analysis, the influence of navigation systems, and the effects of temporary traffic measures in different contexts to further refine traffic management strategies.

Keywords Driving behaviour, Traffic management, Road closures, Static traffic signs, Route choice, Detour Behaviour Model

I. Introduction

The Dutch motorways are experiencing an annual increase in vehicle traffic, resulting in more kilometers driven each year [1]. To keep traffic flowing smoothly, regular maintenance, repairs and capacity expansions are necessary, which unavoidably disrupt traffic flow and cause challenges for traffic management and safety. Effective control measures such as speed limits, lane closures and detours are implemented to mitigate these consequences [2]. These measures affect not only the construction zone but also the surrounding areas. Ensuring the safety of road workers and the smooth flow of traffic during roadworks is a major priority.

Information about road works is communicated to drivers by various methods, including static road signs, variable message signs (VMS) and media announcements [3]. In the Netherlands, static road signs are the main source of information during roadworks, providing details of road closures, traffic changes and diversions. Despite these measures, accidents are still common around roadworks, often involving vehicles colliding with roadworks vehicles such as arrow trucks and bots absorbers [4].

On 24 March 2024, Omroep Brabant [5] published an article calling for the motorway to be completely closed during the construction work and for everyone to be diverted via other roads. Besides measurements showing that 85% of road users drive are speeding along roadworks, the aggressive behaviour of road users towards road workers is another reason for this call. On 23 March 2024, a road worker received a concussion from a bottle thrown at his head from a passing vehicle [6]. These accidents occur despite the many traffic control measures in place around the work zone. However, work is also being carried out where additional measures have not yet been put in place. These include the installation of traffic signs for the upcoming roadworks. In September 2023, there was an alarm call from the road workers installing the traffic signs that something needed to be done about their safety [7]. It was a result of several accidents in which the road workers were not involved but were not responsible. The report followed an accident in which a lorry collided with a work vehicle, injuring the road worker. In another interview conducted by Omroep Brabant [7], it emerges that this kind of accident happens almost every month. This results in that the road workers ensure safety, but at the same time, they are exposed to danger.

In this interview, it is suggested that placing fewer traffic signs could be a start to solving the problem [7]. However, there has been no research into the possibility of using fewer signs. There have been several studies on the effectiveness of traffic control measures and safety in work zones, focusing at the contribution of variable message signs, paragraph III. However, relatively few studies are available on the effectiveness of static traffic signs in providing information about upcoming works, detours and traffic impacts.

As a result of recent accidents involving road workers at risk and the identified research gap, this study aims to determine the influence of temporary static message signs on road user decision-making and driving behaviour around road closures and associated diversions. By developing a theoretical framework describing the decision-making and driving patterns around detours, and by analysing real-time travel behaviour and route choice in two observation studies in The Netherlands, the study contributes to the existing literature on how temporary static signs affect traffic flow around roadworks.

II. Methodology

This paper presents a conceptual framework of detour behaviour and the results of two observational studies of real-time driving behaviour and route choice around a road closure and detour.

The model has been developed using findings from a brainstorming session with experts in temporary traffic management, a literature review and informal discussions with colleagues of Traffic & More specialised in temporary traffic measurements and regular road users. This comprehensive approach ensures that the model reflects real-world driving behaviour and decision-making processes around road closures and detours. The framework was evaluated and refined based on feedback from the brainstorming session participants, providing a thorough understanding of the behavioural dynamics involved in navigating road closures and detours.

The aim of the model is to investigate how drivers respond to temporary traffic measures and to gain a more detailed understanding of detour-related driving behaviour. The construction of the Detour Behaviour Model follows a structured approach and the detours considered are based on the CROW guidelines 96a for traffic management in the Netherlands [8]. The structured approach consists of examining the decision-making process that drivers go through when approaching road closures and diversions. Secondly, the different factors that influence drivers' decision-making and driving style will be assessed. As a result, different driver profiles will be identified based on driver behaviour and decision-making patterns around detours. Finally, the model will capture driving patterns around the road closure and associated detours.

Two case studies were conducted to observe drivers' route choices and speed adjustments around detour signs on the motorway in response to road closures on the secondary road network. The first case study was conducted on the A9 near Schiphol Airport. This study focused on the motorway section before and after exit 6 (Aalsmeer exit) towards Badhoevedorp on the A9, where the road to Schiphol Airport (Schipholweg) was closed beyond the exit. The second case study took place on the A27 near exit 27 (Hagestein exit), where the road to Vianen (Hagenweg) was closed after the exit. The main difference between the two case studies lies in the route options. In the first case, drivers ignored the road closure signs, left the motorway and encountered the closed road, forcing them to turn back to rejoin the motorway to reach Schiphol Airport. In the second case, although the road to Vianen was closed, drivers had the option of taking a shortcut. Route choices are analysed using ANPR (Automatic Number Plate Recognition) cameras by counting vehicles passing one or more camera locations. These licence plates are linked by a script and are not stored to protect the privacy of the road user. In addition, detection loop data from the NDW (Nationaal Dataportaal Wegverkeer) is used to identify changes in driving behaviour in terms of speed adjustments on the motorways around the temporary static traffic signs about the road closure and detour.

III. Literature review

Several studies have evaluated the effectiveness of temporary traffic control (TTC) measures in motorway work zones to improve safety and traffic flow. Li and Bai [3] used logistic regression and significance level analysis to examine various TTC measures such as flaggers, traffic signs, arrow boards and portable variable message signs (VMS). They found that the different measures could control speeds and reduce crashes. However, the effectiveness of individual TTC methods may vary when combined with other traffic control devices or work zone conditions. A driving simulator study by Md Mahmudur Rahman et al. [9] focused on sign design impacts on driver behaviour and safety, revealing that longer frame refresh rates on signs were more effective in influencing drivers' speed and deceleration. They also found that Dynamic Message Signs (DMS) were more effective at night than other signs. Multiple studies, including those by Chatterjee and Mcdonald [10], Horowitz et al. [11], and Erke et al. [12], assessed VMS performance, highlighting its role in reducing queues and congestion despite minimal impact on travel distance. These studies also noted safety concerns due to potential driver distraction.

Research on driving behaviour indicates a range of influencing factors, from individual characteristics to environmental conditions. Ben-Elia et al. [13] emphasised the importance of adopting behavioural assumptions that are relevant to route choice models, demonstrating the significant impact of real-time information and prior experience on decision-making. The studies by Denrell and March [14] and Denrell [15], showed complex patterns in decision-making and risk perception, further validated by Măirean and Diaconu-Gherasim [16], who used a questionnaire to link time perspective with risky driving behaviour. This resulted in participants with higher past negativity and present fatalistic time perspectives reporting more risky driving behaviour, while those with a high future time perspective reported less.

Driver characteristics and demographics also influence behaviour. Munion et al. [17] found gender differences in navigation performance, while Weng and Meng [18] showed that younger and male drivers were more likely to take risks. Zhu et al. [19] examined the behaviour of older drivers and showed a preference for shorter day trips but a higher likelihood of dangerous driving situations. Charlton and Starkey [20] found that experienced drivers had more consistent driving patterns but struggled with speed adjustments at roadworks. Steinbakk et al. [21] linked impulsivity and conformity to norms to higher speed preferences in work zones. Driving style studies by Eboli et al. [22] and Taubman-Ben-Ari and Yehiel [23] found significant effects of behavioural-emotional factors on driving style, highlighting aggressive and careful driving behaviours. Herrero-Fernández [24] and Miller and Taubman-Ben-Ari [25] further explored the relationship between driving style, lifestyle and family dynamics. The influence of navigation systems on driver behaviour was examined by SWOV [26], who found that while these systems reduce stress, they can also distract drivers. Lieke Bos et al. [27] examined users' experiences of roadworks, highlighting the stress caused by unexpected delays and the effectiveness of timely information in reducing inconvenience.

Despite extensive research on digital traffic signs and their impact on work zone safety and detours, the impact of static traffic signs on diverted traffic remains relatively unexplored. Existing studies primarily use simulation-based methods rather than observational approaches, leaving a gap in understanding how static signs influence driver behaviour and route choice during detours.

IV. Detour Behaviour Model

This paper presents a conceptual framework, which provides a structured framework for understanding driving behaviour and route choices in response to road closures and associated detours. It therefore improves the understanding of detour behaviour by demonstrating the expected driving patterns around road closures and associated detours. It also explains driving behaviour and decision-making in the context of temporary traffic measures implemented around road closures and detours. The model is based on five components: detour decisions, detour behaviour factors, driver profiles and driving patterns around detours.

A. Detour decision-making process

Drivers are faced with a wide range of decisions when driving, from routine actions such as accelerating and braking, to more complex manoeuvres such as navigating through traffic or responding to unforeseen circumstances. Each decision has implications for safety, efficiency and the overall driving experience [28]. However, the responses to these decisions show variability based on the individual road user and the situation [29].

As a result of the literature and expert knowledge from the brainstorming session, a definition of the trade-offs and different decisions made by road users regarding diversions and road closures has been identified. The primary decision is whether to follow the diversion or to follow an alternative route. Possible alternatives include deviating from the recommended detour to an alternative route or staying on the intended route despite potential obstacles. Other scenarios include the driver being unaware of a detour, choosing an alternative route, or missing the initiation or route of the detour. Consequently, there are six main situational outcomes following the decision to detour, as shown in Figure 1.

B. Detour behaviour factors

Driving behaviour is influenced by a wide range of factors and the corresponding decision-making process involved in driving is complex [30]. Complexity occurs because driving performance and route choice are also influenced by the driver's age, emotional state, task complexity, stress and time pressure, as well as trip attributes such as travel time, distance and traffic conditions [31]. The decision processes discussed include the choice of whether or not to follow a detour. The decision to follow a detour is influenced by various factors, which are grouped into three main categories.: psychosocial, contextual and economic factors.

Psychological factors play a crucial role in the decision-making process of road users as they navigate changes in the road network and adapt to new situations [32]. This process involves a range of cognitive and emotional activities that influence how individuals assess risks, evaluate options and respond to information about new situations while driving [22]. In addition, individual driver characteristics can influence behaviour in unfamiliar scenarios [33]. The category of psychosocial factors includes the driver's psychological, individual characteristics and social circumstances. Environmental, infrastructural and situational contexts also influence driving behaviour and decisions and are included in the category of contextual factors. In addition, detours change the driving conditions and make the task more difficult, not only from a navigational perspective, but also in terms of economic considerations such as time and distance differences, resulting in elements in the economic factors category.

Based on the complexity of the driving task and decision processes and the different factors influencing them, different factors have been identified and assigned to the three categories. Table 1 shows the diversion behaviour factors defined in the categories.

C. Detour driver profiles

The different factors influence driving behaviour and decision making, but also result in different driving styles around a detour. By considering detour decisions and driving styles in these scenarios, detour driver profiles can be developed. These are defined based on possible detour decisions, resulting in four different driver profiles, each associated with corresponding driving styles likely to be encountered around road closures.

Existing research highlights personal characteristics such as gender, age and emotional state as contributors to driving style [32]. Studies categorise driving styles into wide groups: average, aggressive and conservative [34, 35]. More nuanced classifications introduce categories such as reckless and careless driving, anxious driving, angry and hostile driving, and patient and cautious driving [36, 37]. For the context of motorway detours, driving styles specific to detour scenarios were developed using insights from the brainstorming session. This resulted in driving style profiles based on the driver's experience and familiarity with the area. The categories identified include the alert (experienced) driver, the distracted or reckless driver, the uncertain (less experienced) driver and the average driver.

Comparison of these profiles with the existing literature reveals both overlaps and unique distinctions. For example, the 'distracted or reckless driver' is consistent with the 'reckless and careless driver' and 'angry and hostile driver' categories in the literature, but includes more nuanced subtypes. Conversely, specific profiles such as the 'alert experienced driver' are not explicitly covered in the literature. The brainstorming session also identified general driving styles: Average Driver (frequent and confident driver), Conservative Driver and Habitual Driver (driver familiar with the surroundings). As a result, four general driving styles are identified in the

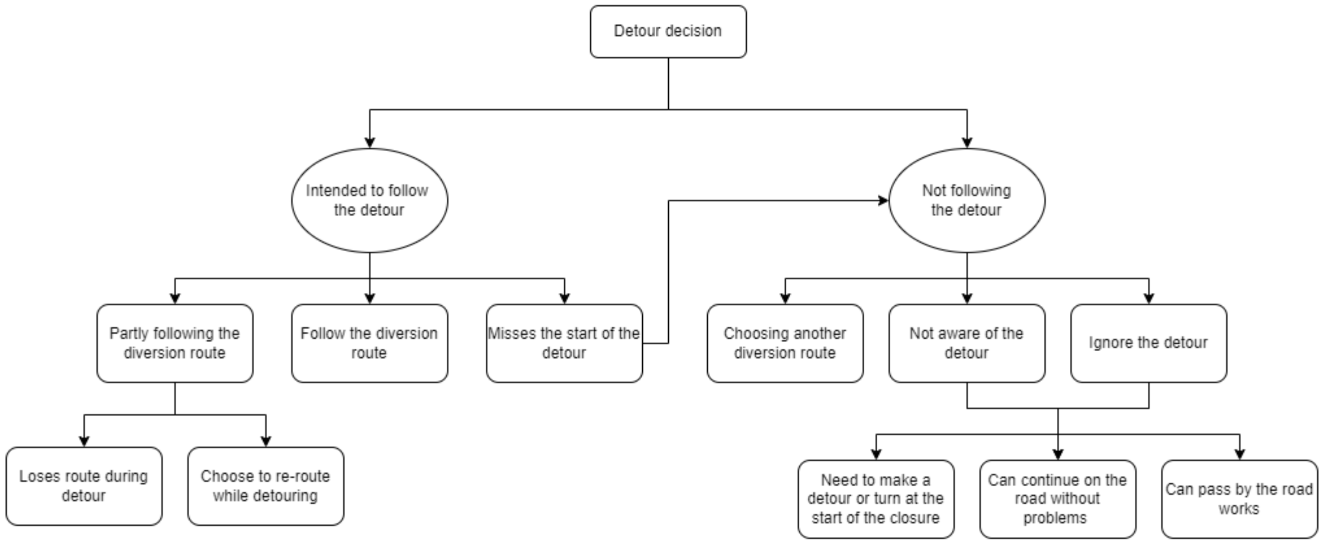

Figure 1. Detour decisions approaching road closures

Table 1. Factors influencing compliance with road closure and detours

Psychological factors		**Contextual factors**		**Economic factors**
Socio-demographic	Emotional state	Road conditions	Light conditions	Distance differences
Risk perception	Vehicle characteristics	Weather conditions	Traffic congestion	Extra costs
Social distraction	Time pressure	Speed limit	Time of the day	Time differences
Situation awareness	Famility area	Roadwork activity	Number of lanes	
Time perception	Use of navigation	Traffic volumes		

context of detour behaviour: Aggressive Driver, Average Driver, Conservative Driver and Habitual Driver.

As a result of the decision-making process six primary scenarios concerning detour decisions are identified, Figure 1, which arise from the choice to either follow the detour or not. However, revealed preference measures are limited in their ability to distinguish whether a driver is unaware of the detour, intentionally disregards the detour, or misses the start of the detour when not following the signs. In addition, the ability to determine whether traffic is partially following the detour depends on the measurement locations. Furthermore, the underlying motivations behind drivers' decisions remain unmeasured. As a result, the main responses of driver are categorised into three main choices:

1) Following the detour
2) Ignoring the detour
3) Choosing an alternative route

In addition to the temporary signs placed during the closure, a pre-notification sign will be placed at the closure location two weeks in advance. Drivers using the road during this period will be informed of the time and duration of the closure so that they can adjust their plans accordingly. Such adjustments may include changing their departure time, staying at home or taking an alternative route to their destination. However, these alternative actions are not captured in the revealed preference experiments conducted during the closure period. Consequently, this scenario introduces additional potential behaviours around a detour. Based on the identified scenarios, four different driver profiles can be developed. These driver profiles are linked to potential corresponding driving styles based on the results of the brainstorming session, shown in Table 2.

D. Driving patterns around detours

Drivers will encounter various traffic control measures, divided into announcement, diversion and closure zones. The study focuses on a complete road closure within the motorway secondary road network. Around the road closure and the associated detour, the different possible driving patterns are investigated to develop the Detour Behaviour model. The study focuses on possible

Table 2. Expected driving styles for each driver profile
x: Expected driving styles

Driver profiles	**Driving styles**			
	Aggresive driver	**Conservative driver**	**Habitual driver**	**Average driver**
Driver profile 1: Following the detour		x	x	x
Driver profile 2: Not following the detour	x		x	
Driver profile 3: Choosing an alternative route			x	x
Driver profile 4: Decision to avoid closure location			x	

movements and routes around traffic signs and road closures. In addition, three possible speed scenarios are identified: reduce, maintain or increase. The closure process is divided into five phases: business as usual, pre-notification, pre-closure, closure and post-closure. Each phase can involve different behavioural patterns, covering behaviours like following or disregarding temporary signs and using alternative routes.

E. Design of Detour Behaviour Model

The detour behaviour model, shown in Figure 2, combines the identified driving patterns and driver profiles. It illustrates the decisions drivers make around a closure and their associated driving patterns. These decisions are influenced by psychosocial, contextual and economic factors, resulting in different behaviours during the five phases of a road closure.

V. Results A9 Case Study

The first case study examines the closure of the Schipholweg near the Aalsmeer exit on the A9 towards Badhoevedorp, focusing on traffic behaviour around the closure. The aim was to investigate how traffic interacts with static temporary traffic signs, in terms of speed adjustments on the motorway and whether road users take the exit to the closed road or another route. Measurements were taken on the motorway using four detection loops in the vicinity of the traffic signs. In addition, ANPR cameras were positioned at the entry and exit ramps to identify non-compliant vehicles. This setup, shown in Figure 3, provided data on the impact of traffic management measures for road closures on the secondary road network.

Measurements were taken between 19:00 and 05:00 during road works on 6-7 and 8-9 February 2024. Both nights were divided into three distinct phases: the pre-closure phase, the closure phase and the post-closure phase. Based on the three different phases, the behaviour around the closure and the informative temporary traffic signs were analysed. Three different traffic flows are measured in this case study, shown in Figure 4. Vehicles travelling on the motorway (blue), vehicles travelling towards the Nieuwemeerdijk via Exit Aalsmeer (green) and vehicles travelling from the motorway towards the Schipholweg, but turning back towards the motorway, because the road is closed (pink). These traffic flows indicate the route choices made by vehicles that do not follow the traffic signs placed due to the closure, or which vehicles make a different choice than using the Schipholweg.

Based on the measurements, a range of vehicles following or not following the diversion was established, the results are shown in Figure 5. During the pre-closure phase, there is no unusual traffic behaviour in terms of route choice and no vehicles reversing at the roundabout, as the Schipholweg remains open to traffic. The pre-closure for the night of 8-9 February ends at 20:28, resulting in two distinct periods between 20:00 and 21:00. However, the available data did not distinguish between the pre-closure and closure phases during this period, so this hour shows different results compared to the pre-closure period between 19:00 and 20:00. On 8 February, vehicles turn around between 20:00 and 21:00. During the pre-closure period, a decrease in the average hourly speed is observed on both nights, which is due to traffic measures on the motorway, including a lower speed limit.

During the closure phase on the night of 8 to 9 February (21:00 - 03:00), when the Schipholweg was closed, there was an above-average amount of traffic on the motorway. The closure of the Schipholweg leads to a decrease in the number of vehicles on the entry and exit ramps in Aalsmeer, with counts similar to the minimum values found in 2024. No significant difference was found between the average traffic volumes in 2024 and the traffic volumes for the closure phase on 6 and 7 February (20:00

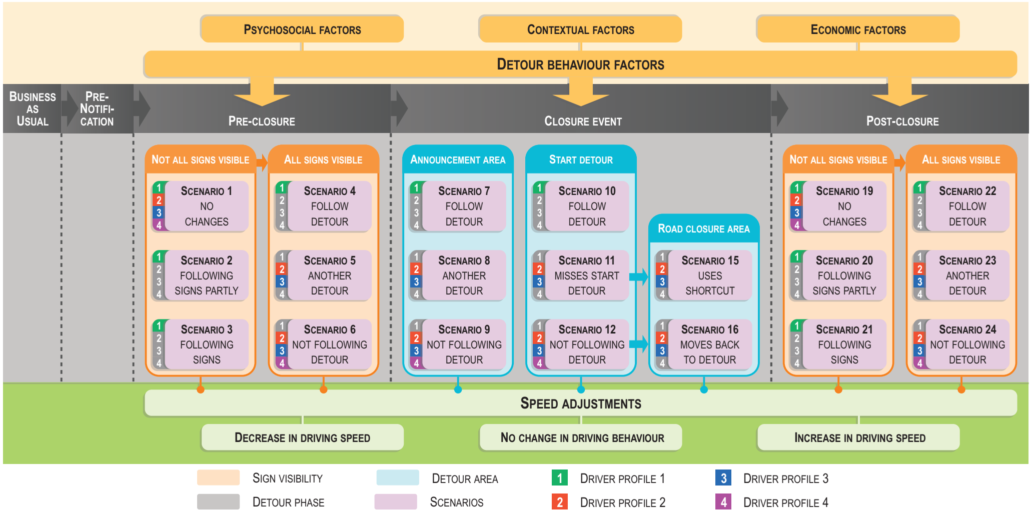

Figure 2. Detour Behaviour Model

Figure 3. Study area A9

–: Detection loops

red-white stripe: road closure

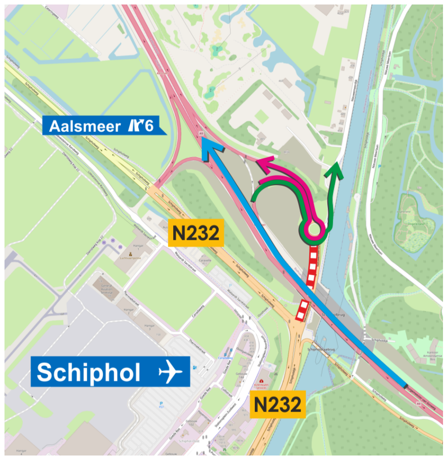

Figure 4. Traffic flow detections

Pink arrow: vehicles turned back towards motorway

Green arrow: vehicles towards Nieuwemeerdijk

Blue arrow: vehicles travelling on the motorway.

Red-white band: road closure

- 04:00). Due to the closure and the associated traffic measurements, the null hypothesis was that vehicles heading towards the Schipholweg would not use the exit ramp. However, the ANPR camera measurements show that a significant proportion of vehicles turn around at the roundabout to return to the motorway. Throughout the entire closure period over both nights, the percentage of vehicles that do not comply with the measures and still use the exit ranges from 18.3% to 73.8%. This range is determined by comparing the number of vehicles that turned at the roundabout due to the closure of Schipholweg with the expected number of vehicles on the exit ramp (18.3%) and further specifying the number of vehicles from this group that were expected to head towards Schipholweg (73.8%).

The post-closure phase occurs after the Schipholweg has been reopened to traffic and the temporary traffic signs have been removed. For the night of 8-9 February, as in the pre-closure phase, the data did not distinguish the time at which the road was reopened at 04:18. As a result, between 04:00 and 05:00, vehicles were still turning around because of the closed Schipholweg. Therefore, it is possible that these turning vehicles are turning between 04:00 and 04:18 and no vehicles are turning back to the motorway between 04:18 and 05:00, but this cannot be said with complete certainty due to data limitations. For

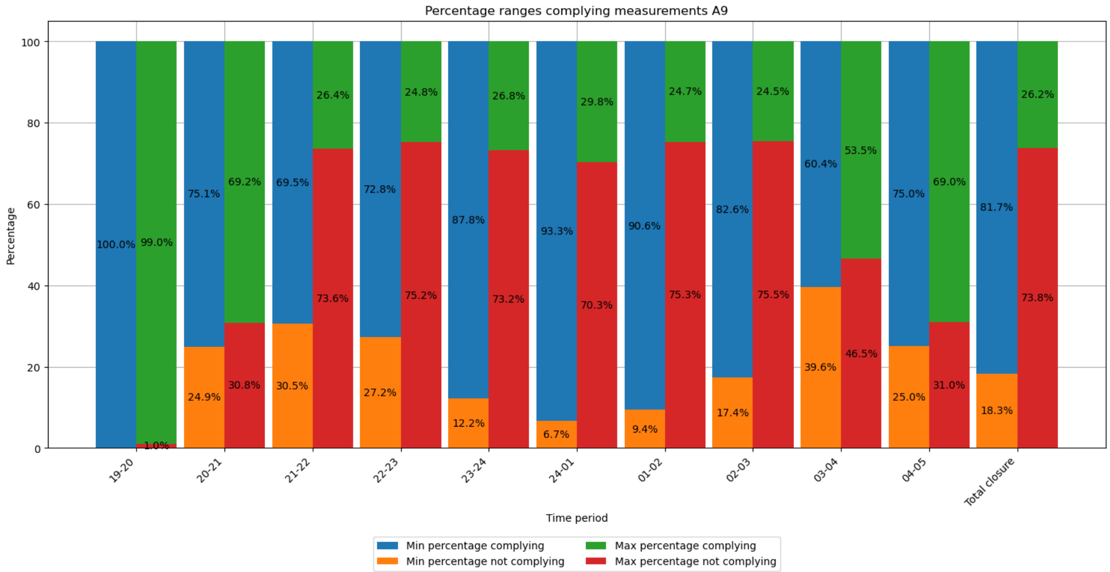

Figure 5. Percentage ranges complying with measurements for the nights of 6-7 and 8-9 February A9
Min percentage: percentage of vehicles compared to expected vehicles exit Aalsmeer
Max percentage: percentage of vehicles compared to expected vehicles Schipholweg
Total closure: percentage of vehicles complying with measures between 21:00 - 03:00

the night of 6-7 February, it is clearer that this behaviour decreased after the reopening of the road. On this night, the road reopened at 03:05, which means that the road is available for traffic for a significant part of the hour, which leads to a decrease in the percentage of vehicles making a turn. In addition, the motorway traffic volume results show that the number of vehicles on the on- and off-ramps increases again during the post-closure period.

VI. Results A27 Case Study

A second case study is conducted to understand the influence of static road closure and diversion signs and which routes are chosen by road users. To study how traffic behaves around a closure and how it reacts to static traffic signs, the access road to Vianen, Hagenweg, was closed on the secondary road network of the A27 motorway.

There are three possible traffic flows around the closure due to traffic coming from the motorway in the direction of the (closed) Hagenweg. These include the indicated detour on the motorway as shown in Figure 6. In addition, two alternative traffic flows may occur during the closure of Hagenweg. Therefore, the second route analysed is the shortcut. On this route, traffic heading for Vianen still takes the Hagestein exit, despite the temporary traffic signs. After the exit, the traffic heads towards Lange Dreef to continue to Vianen. Finally, the traffic that initially takes the Hagestein exit turns around at the roundabout to take the detour to the Nieuwegein exit and access ramp. The different routes were analysed using ANPR camera measurements. Measurements were taken on four Tuesday evenings between 20:00 and 04:00, on the nights of 27 February and 28 February, 5 and 6 March, 12 and 13 March, and 19 and 20 March. The Hagenweg is closed from 21:00 until 04:40 in the night of 27 and 28 February and on 12 and 13 March.

Four ANPR cameras were used for the case study and to monitor the traffic routes. These were placed at Afrit Hagestein, Afrit Nieuwegein, Oprit Nieuwegein and Lange Dreef, as shown in Figure 6. The ANPR cameras count the number of vehicles passing each location based on their number plates. In addition, by recording the number plates, the cameras can identify which vehicles have been detected at multiple locations within a given time period, providing information about the routes travelled. Traffic on the motorway was analysed using NDW data retrieved from the detection loops, shown in Figure 7. This data includes hourly traffic volumes and average speeds, allowing for an analysis of traffic behaviour around the closure. These detection loops can also determine the number of vehicles on the exit ramps at Hagestein and Nieuwegein.

Similar to the A9 case study the behaviour of vehicles was observed around the closure for three different phases: pre-closure, closure and post-closure. The route choices are conducted hourly for the entire closure period. The

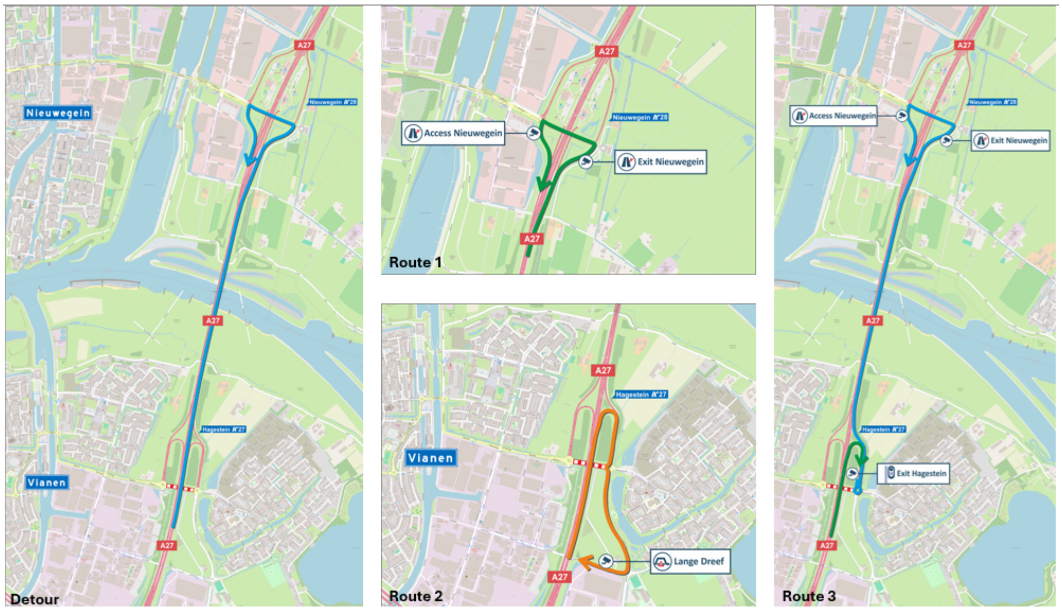

Figure 6. ANPR camera locations and possible routes case study A27
Route 1: Detour associated with road closure
Route 2: Not following the detour and taking the shortcut
Route 3: Taking the exit to turn back to the detour

percentages of route choices around the road closure are shown in Figure 8.

The pre-closure phase is the period between 20:00 and 21:00. During this period, the Hagenweg was not closed and traffic signs along the motorway became visible to traffic during this hour. On both days, no vehicles were seen on routes 2, 3 and 4 during these periods. This can therefore be explained by the fact that the Hagenweg was open, so that those travelling in this direction did not encounter any hindrances. The percentages of vehicles observed on Route 1 differed between the two days, likely due to variations in the visibility of road signs. On 27-28 February, the signs were visible earlier, providing a longer period for vehicles to follow the detour on Route 1.

The closure phase lasted from 21:00 to 04:00 on both nights. This phase was analysed on an hourly and cumulative basis (Total closure) for the entire period. The total number of vehicles detected during these hours (closure) was also calculated. The differences between Total Closure and Closure are minimal, indicating that the proportion of vehicles avoiding Hagenweg by staying home or taking an alternative route is limited. This results in that the overall percentages for both nights are very similar, showing that a significant proportion of vehicles around a closure do not follow the detour or signage. Approximately 33% of vehicles follow the diversion signs, while 60% do not. Of these 60%, 4% return to the indicated detour when encountering the closure and the remaining 4% avoid the closure by staying at home or taking an alternative route. This 4% avoidance of the Hagenweg is based on the expected vehicles that will use this road when it is not closed, therefore they are assumed to avoid the closed road.

The post-closure phase took place between 04:00 and 05:00. The road closure was released at 04:40 on both days. The Hagenweg remained closed for the first 40 minutes of the hour, with vehicles being directed to follow the detour. The Hagenweg was reopened for the last 20 minutes of the hour. As no measurements were taken on the Hagenweg during this time, it is not possible to determine how many vehicles were using the Hagenweg. Consequently, a detailed analysis of traffic behaviour when the closure was removed but the traffic signs remained in place is not possible. Therefore, the percentages for route choice are based on the expected number of vehicles and the number of vehicles observed on the routes. On both 12 and 13 March, no vehicles continued their journey via route 1, the Nieuwegein exit.

In addition to the ANPR measurements, a number of analyses were carried out using data from the detection loops on the motorway, Figure 7. During certain periods, the observed traffic volumes were higher than average. Specifically, on 27 and 28 February, the Nieuwegein exit recorded increased volumes until midnight, and on 12

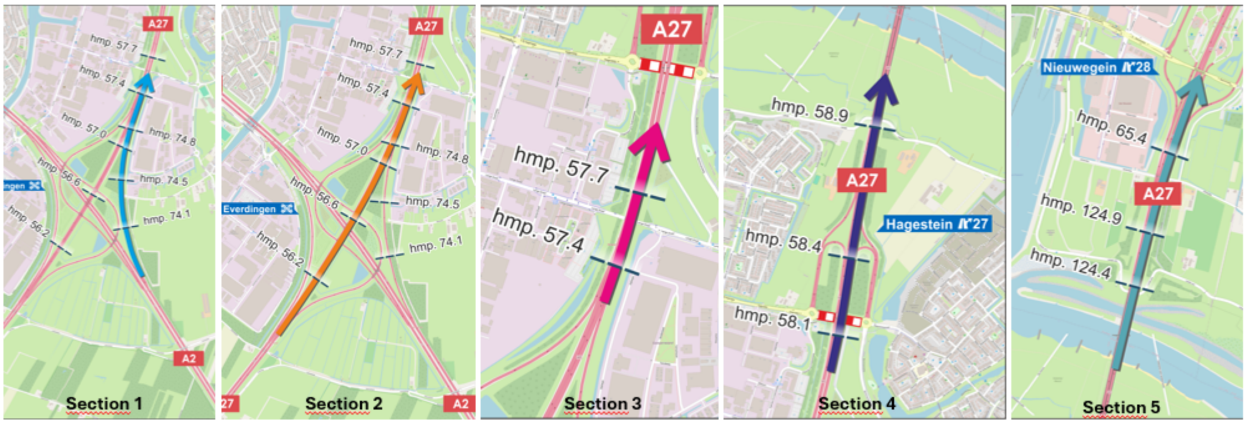

Figure 7. Detection loop measurements
–: Detection loop

and 13 March this trend continued for up to two hours. However, at the Hagestein exit, the differences were less striking and were only noticeable until 23:00 on 12 March. These higher traffic volumes may have influenced the number of vehicles using alternative routes due to the closure of the Hagenweg. As a result, this could lead to small fluctuations in the percentage of vehicles using the detour, although these differences are expected to be minor. This is supported by the fact that there were no significant deviations from the measured values on 19 March for vehicles using alternative routes. The average speed per hour was also determined and analysed for different sections of the motorway. The average speeds found around traffic signs and exits show no clear speed adjustments for all phases and time periods. Therefore, only changes in driving behaviour are visible in terms of route choice.

VII. Discussion

A. Results interpretation

The analysis of the A9 and A27 case studies shows significant differences in the route choices made by drivers encountering road closures. In the A9 case study, route choice is primarily determined by whether vehicles pass the exit in the direction of the closed road. Vehicles that bypass the exit are classified as following the diversion, but their final destinations and exact routes remain uncertain. Some vehicles may use alternative routes not captured in the analysis. In contrast, the A27 study offers a more detailed examination of the different route options available to drivers, providing a more nuanced understanding of route choices.

The A27 case study benefits from a more detailed analysis of the pre-determined possible routes through the closure, assuming that the three closest and shortest alternatives cover most choices. Although other potential routes are not considered, this study provides a more accurate understanding of traffic flows and compliance rates. Non-compliant vehicles in the A9 case are those that returned to the motorway after taking the exit, while for the A27, it is those that returned to the motorway after taking the Hagestein exit to use the Nieuwegein exit (Route 3). At least 4% of vehicles in the A27 case and a range 18.3% - 73.8% in the A9 case did not follow the signs at all. The lower percentage for the A27 is due to 60% of vehicles taking a shortcut after the exit ramp, resulting in a total non-compliance rate of 64%. The range for the A9 case study is determined by comparing the number of vehicles that turned at the roundabout due to the closure of the Schipholweg with the expected number of vehicles on the exit ramp (18.3%) and further specifying the number of vehicles from this group that were expected to head towards the Schipholweg (73.8%).

Combining the results from both case studies gives a range of non-compliance from 18.3% to 73.8%. A detailed analysis of route choice from the A27 case shows a non-compliance rate of 64% during the closure phase, which falls within this range. However, the 18.3% rate appears to be a low estimate. A more accurate assessment suggests refining the non-compliance range to 64% to 73.8%, focusing on vehicles expected on the closed road and those not following diversion signs.

In both studies, the percentages of route choices are based on expected and measured vehicle numbers. Expected vehicle numbers, determined by linear regression, help to estimate normal conditions. However, the undefined distribution between work, local and occasional traffic makes it difficult to accurately estimate the number

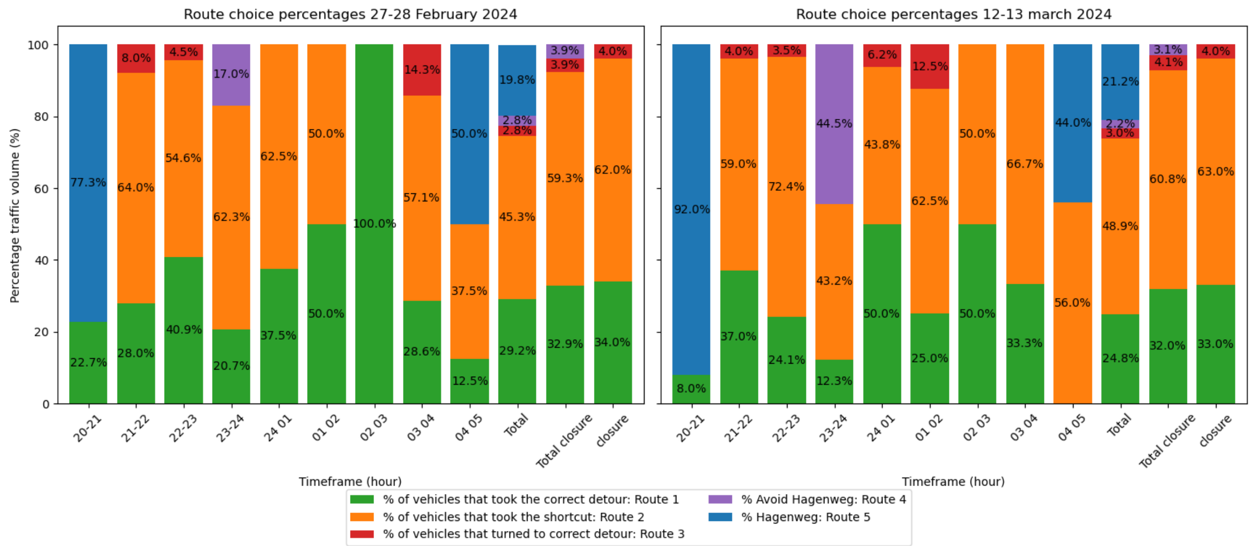

Figure 8. Route choices by closure Hagenweg A27

Total closure: total route choices during closure phase 21:00 - 04:00
closure: route choices during closure phase detected vehicles 21:00 - 04:00

of diverted vehicles.

Due to data limitations, it is not possible to determine the average speed dynamics of individual vehicles, so only the overall effect of temporary traffic measures on motorway traffic can be assessed. As the closure affects the secondary road network, not all traffic is affected, which may underestimate the effect of temporary measures. In the A9 study, observed speed changes could also be due to additional measures such as lane closures and reduced speed limits around the exit, making it difficult to isolate the effect of temporary signs.

B. Detour Behaviour Model

The conceptual model framework, created to analyse the behaviour of road users around motorway diversions was mainly based on existing literature and the brainstorming session. The Detour Behaviour Model consists of several components: the Detour Decision Process, the Detour Behaviour Factor, and Driving Styles, from which driver profiles and driving patterns around detours are derived. The designed model was then presented to the same participants from the brainstorming session in order to validate the model. Despite the validation by the brainstorming participants and the evaluation of the model against the case studies, some components of the model were not tested further.

Firstly, the research did not test the factors influencing route choice and driver behaviour individually. Instead, it examined a wide range of factors and grouped them into three categories: psychosocial, contextual and economic. While the impact of these factors on individual detour decisions and their interactions was not fully assessed, the study did explore economic and contextual factors based on case study results. Although the exact relationship between these factors and detour decisions could not be determined, the research provides valuable insights into the factors that influence driver behaviour.

The developed model includes four types of driver profiles relevant to detours, integrating potential factors, decision-making processes and different driving styles. However, the lack of individual driver identification in observations limits a comprehensive understanding of the factors influencing these profiles and associated driving styles. Despite this limitation, route choice analyses allow the identification of driver profiles based on route choices. While not all derived driving behaviour scenarios were found in the case study results, the scenarios were tested with one type of closure, leaving open the possibility of different outcomes with alternative types of road closure, such as motorway closures.

Overall, the Detour Behaviour Model provides a structured framework for evaluating the complex dynamics surrounding detours and road closures. While observational studies can be conducted without the model, it provides deeper insights into route choice and road user behaviour by identifying and understanding four distinct driver profiles and their decisions in response to detours. Case study evaluations have demonstrated the effectiveness of the model in understanding different scenarios during road closures.

C. Limitations

By selecting two case studies for an observation study, this research aimed to provide valuable insights. However, it is important to recognise and address certain limitations associated with this study that are not already discussed in the interpretation of the results.

Firstly, the closures in both case studies were on secondary networks, limiting the understanding of driver behaviour in response to alternative closures. In addition, the study period was limited to specific nights in February and March 2024, which may not accurately represent typical traffic patterns throughout the year. Seasonal variations or specific events during these nights could influence the results. In addition, the data available for analysis may have been limited to a shorter time period, limiting the ability to identify and understand long-term trends in road closure and diversion behaviour.

It is important to recognise the influence of non-quantifiable factors such as navigation systems on route choice behaviour and compliance with diversion signs. Navigation systems play a valuable role in guiding drivers during road closures, but their impact on route choice and compliance is difficult to measure. This study does not take into account whether drivers were using navigation systems, their activation status, or compliance with suggested routes. In addition, navigation systems allow for dynamic route adjustments based on real-time traffic conditions, which may deviate from predetermined detour routes indicated by signage. While these effects cannot be directly measured in this research, they remain important considerations in understanding and interpreting observed route choice and compliance behaviour during road closures.

D. Generalisation of Results

This research has provided a comprehensive conceptual framework for understanding the behaviour related to road closures and associated detours. The resulting detour behaviour model has the potential for broader application beyond the specific scenarios analysed in this study.

The framework presented in Figure 2 is developed from considerations of a full road closure within the secondary road network adjacent to a motorway exit. The model is based on the assumption that road closure information is presented along the motorway, but is not limited to one location. This assumption allows the model to be useful for traffic managers in anticipating and managing the various situations that can arise in relation to road closures and the diversion of vehicles travelling from the motorway.

In addition, looking at traffic flows on the motorway and the route choices made based on the information displayed on the temporary traffic signs. The findings show that during road closures, a significant proportion of vehicles do not follow the diversion signs but choose to continue in the direction of the closed road. Both case studies focus on access road closures within the secondary network, differing in terms of the availability of alternative detours after exiting the motorway. The results show a baseline of 18.3% of traffic not complying with motorway detours during closures, with this number increasing to an average of 65 - 73.8% throughout the closure period when alternative routes are available. The study therefore shows that, in general, when considering compliance with temporary traffic measures for road closures on the secondary road network, there is an identifiable number of drivers who do not comply with these measures.

E. Comparison Results with Literature

This study provides knowledge on compliance with static diversion signs during road closures, whereas the literature mainly focuses on the effectiveness of dynamic route information systems such as variable message signs (VMS). Although there are limited directly comparable studies, some comparisons can be made with findings from previous studies.

Chatterjee and Mcdonald [10] investigated drivers' responses to VMS in urban areas. The VMS provided route guidance to improve the efficiency of the road network and as a result, they found an overall compliance rate of 92% to the information. This compliance rate is significantly higher than the rate found towards detour information in this study. Other studies identified lower compliance ratios. Erke et al. [12] investigated the impact of route guidance VMS on speed and route choice on motorways, resulting in a higher proportion of vehicles of approximately 20% changing their route. Davidsson and Taylor [38] examined VMS which suggested alternative routes to avoid congestion, with 6-41% driver response rates. Additionally, Ramsay and Luk [39] shows that announcing a road closure increases the number of vehicles diverted by 30%. The A9 case study shows a minimum compliance rate with the measures of 26.2%. In the case study of the A27 of the Hagenweg closure, an overall compliance rate to the indicated detour showed a similar proportion of diverting vehicles of 32%. This percentage is higher than the previous values found, but this is based on the road being closed and the previous percentages were based on vehicles taking a detour when the road remains open.

Desai et al. [40] analysed diversion patterns associated with unplanned road closures on major motorways. By examination of 12 case studies, they found that choosing another route rather than staying on the base route is in the range of 58% to 93% for road closures exceeding five hours. The range of alternative route choices obtained from the A9 case study can be determined. The percentage of people choosing an alternative route instead of trying to use the intended route showed an overall range from 26.2% to 73.8%. This range is wider and has a lower maximum value than the range found, but the maximum value is within the range found [40].

VIII. Conclusion and Recommendations

By conducting two observational studies of route choice and driving behaviour, it reveals the complex dynamics between static traffic signs and drivers' route choices. Furthermore, it presents a systematic conceptual framework for interpreting the detour behaviour of road users, contributing to the traffic management literature. Moreover, the integration of the detour behaviour model with observational findings has resulted in the identification of four distinct driver profiles among road users encountering detours: following the diversion, not following the diversion, choosing an alternative route or avoiding the closed road area.

The empirical findings from two case studies of access road closures in the secondary road network showed that a significant proportion of drivers, ranging from 64% to 73.8%, did not follow the detour signs. Instead, these drivers either attempted to continue on their original route towards the closed road or decided to take available shortcuts. This behaviour demonstrates the limited effectiveness of temporary signs in influencing a significant proportion of motorway drivers.

The observed low compliance rate has practical implications, requiring adjustments to current traffic management systems to direct more drivers to diversion routes. This research was motivated by several accidents involving road workers installing diversion signs. This emphasises the need to review and improve sign placement strategies to ensure the safe diversion of all traffic around roadworks and the safety of road workers installing the signs. Given the low compliance with static diversion signs and the high risks associated with their placement, it is recommended to explore and implement alternative methods of traffic control. This could include the use of dynamic, real-time information, such as smart traffic systems and mobile applications, to guide road users more effectively and improve the safety of road workers. By focusing on road user route choices and driver profiles through the Detour Behaviour Model, proactive measures can be developed, ensuring that traffic management strategies are more closely aligned with actual route choices.

A. Future research

Future research is recommended to improve and extend the applicability of the detour behaviour model. Evaluating the effectiveness of the model beyond full closures on secondary road networks, and adapting it to urban settings, can enhance its validation and robustness. Further evaluation of the identified factors influencing decision-making and driving behaviour, and investigation of their correlations and interactions, will further improve the understanding of driving patterns around road closures. In addition, driver profiles and driving styles can be further defined by investigating the associated factors. The use of qualitative methods such as surveys and interviews can reveal drivers' motivations, perceptions, preferences and attitudes towards detour signage and route choice, and contribute to the development of a more comprehensive model of detour behaviour.

Future research into the effectiveness of different traffic management strategies has the potential to improve the efficiency and safety of road closures. Conducting controlled experiments or observational studies in different roadworks environments to investigate optimal sign configurations and communication strategies can improve the understanding of the effective provision of detour information and compliance rates. Exploring the implications and possibilities of navigation systems is another interesting area for future research. Investigating how drivers use guidance systems to influence route choice and their potential to override traditional signage could lead to new traffic management strategies. In addition, the impact of navigation systems on the attention of the road user to traffic signs and the road situation enhances the knowledge of factors influencing driving behaviour.

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Appendix A Literature overview

A.1 Research aspects in previous studies

	Work zone safety	Traffic management	Traffic Hindrance	Travel behaviour	Navigation systems	Route choice	Dynamic message signs	Advanced Travel Information Systems	Real-time information	Graphic Route Information Panels	Dynamic Route-information panel	Static signs	Variable message signs
Literature							Traffic control measures						
S.J. van Leeuwen	*			*	*	*						*	
Bai, Finger, and Li [7]	*	*			*		*				*	*	*
Al-Bayati, Ali, and Nnaji [8]	*	*											
Li and Bai [75]	*	*		*			*				*	*	*
Shahin, Elias, and Toledo [116]		*		*			*						*
Md Mahmudur Rahman et al. [84]				*			*					*	*
Silveira et al. [117]		*		*									
Chatterjee and Mcdonald [17]				*									*
Horowitz, Weisser, and Notbohm [52]				*		*							*
Erke, Sagberg, and Hagman [38]				*									*
He et al. [47]				*		*							
Vrieling, Waard, and Brookhuis [139]	*			*					*				
Kattan, Barros, and Saleemi [63]						*		*					
Reinolsmann et al. [103]						*		*		*			*
Lee and Kim [70]	*			*				*	*				
Lee, Kim, and Harvey [71]	*			*				*	*				
Chen et al. [19]						*			*				
Heutinck et al. [49]							*						
Spiliopoulou et al. [119]													
Gallo, Dougald, and Demetsky [41]		*		*	*								
Sullivan et al. [122]	*	*		*					*				
Allen et al. [4]				*	*								
Halati and Boyce [46]					*	*	*						
Cristea and Delhomme [23]				*	*	*							
Knapper et al. [66]				*	*				*				
Metz [85]				*	*								
Wansink and Ittersum [140]	*	*											
Morris and Trivedi [88]		*		*	*			*					
Hu et al. [53]				*	*								
Kim, Liu, and Chang [65]				*		*			*				
Morshedi et al. [89]				*		*			*	*			
Desai et al. [29]					*	*							
Leuisnk [73]				*	*	*							
Hway-liem [55]									*				
Monitor Smart Mobility 2023 [87]			*										
SWOV [126]			*		*								
Lieke Bos et al. [76]	*		*										
SWOV [125]		*	*	*									
Beijer, Smiley, and Eizenman [9]	*		*	*									

Chattington et al. [18]	*		*	*	*	*							
Oviedo-Trespalacios et al. [96]	*		*	*									
Dicke-Ogenia, De Munck, and Hazelhorst [31]	*		*	*	*		*	*					
Kurzhanskiy and Varaiya [69]		*				*							
Brügger, Richter, and Fabrikant [13]					*	*		*					
Ben-Elia, Erev, and Shiftan [10]				*		*			*				
Denrell [27]				*		*							
Denrell and March [28]				*		*							
Katsikopoulos et al. [62]				*									
Dia and Panwai [30]				*		*							*
Jensen, Skov, and Thiruravichandran [57]				*		*		*					
Acharya and Mekker [2]					*								*
Zhu, Jiang, and Yamamoto [149]				*									
Jou et al. [59]				*					*				*
Adler [3]				*		*							
Măirean and Diaconu-Gherasim [82]				*					*				
Weng and Meng [142]				*					*				
Charlton and Starkey [16]				*									
Strawderman, Huang, and Garrison [121]							*					*	*
Jung and Bell [60]				*	*			*					
Kim et al. [64]						*			*				*
Ciscal-Terry et al. [22]						*		*					
Brookhuis and Dicke [12]				*	*	*							
Ringhand and Vollrath [111]	*	*				*			*				
Koller-Matschke, Belzner, and Glas [68]				*	*	*			*				
Uang and Hwang [133]				*	*				*				
Munion et al. [90]				*		*		*					
Steinbakk et al. [120]				*									
SWOV [126]	*											*	
Vignali et al. [137]	*												
Taubman-Ben-Ari, Mikulincer, and Gillath [130]				*									
Sagberg et al. [115]				*									
Rong, Mao, and Ma [114]				*									
Sun et al. [124]				*									
Xing et al. [146]				*									
Liu et al. [78]				*									
Qi et al. [101]				*									
Huysduynen et al. [54]				*									
Eboli, Mazzulla, and Pungillo [33]				*									
Johnson and Trivedi [58]				*									
Taubman-Ben-Ari and Yehiel [129]				*									
Miller and Taubman-Ben-Ari [86]				*									
Herrero-Fernández [48]				*									
Chen and Chen [20]				*									

Table 57: Research aspects in previous studies

A.2 Methods used in previous studies

	Literature Analysis	Conceptual framework	Linear mixed effect models	Regression Analysis	Comparative analysis	Micro Simulation	Macro Simulation	Driving Simulator	Case study	Survey	Multi-criteria anlaysis
Literature				Revealed preference						Stated preference	
S.J. van Leeuwen	*	*			*				*		
Bai, Finger, and Li [7]					*				*		
Al-Bayati, Ali, and Nnaji [8]	*										
Li and Bai [75]				*							
Shahin, Elias, and Toledo [116]			*					*			
Md Mahmudur Rahman et al. [84]			*					*	*	*	
Chatterjee and Mcdonald [17]							*			*	
Horowitz, Weisser, and Notbohm [52]									*		
Erke, Sagberg, and Hagman [38]				*					*		
He et al. [47]						*					
Vrieling, Waard, and Brookhuis [139]									*	*	
Kattan, Barros, and Saleemi [63]										*	
Reinolsmann et al. [103]								*		*	
Lee and Kim [70]									*	*	
Lee, Kim, and Harvey [71]									*	*	
Chen et al. [19]						*	*				
Heutinck et al. [49]						*					
Spiliopoulou et al. [119]							*				
Gallo, Dougald, and Demetsky [41]						*			*		
Sullivan et al. [122]										*	
Allen et al. [4]						*					
Halati and Boyce [46]						*					
Cristea and Delhomme [23]								*			
Knapper et al. [66]										*	
Metz [85]	*										
Wansink and Ittersum [140]	*	*									
Morris and Trivedi [88]		*		*	*				*		
Hu et al. [53]				*	*						
Kim, Liu, and Chang [65]								*		*	
Morshedi et al. [89]		*								*	*
Desai et al. [29]						*			*		
Leuisnk [73]					*	*					
Hway-liem [55]										*	
Monitor Smart Mobility 2023 [87]										*	
SWOV [126]											
Lieke Bos et al. [76]										*	
SWOV [125]	*										
Beijer, Smiley, and Eizenman [9]								*			
Chattington et al. [18]	*										
Oviedo-Trespalacios et al. [96]	*										
Dicke-Ogenia, De Munck, and Hazelhorst [31]					*				*	*	
Kurzhanskiy and Varaiya [69]							*				
Brügger, Richter, and Fabrikant [13]									*		
Ben-Elia, Erev, and Shiftan [10]								*			
Denrell [27]	*	*									

Denrell and March [28]		*	*					
Katsikopoulos et al. [62]						*		
Dia and Panwai [30]					*			*
Jensen, Skov, and Thiruravichandran [57]							*	
Acharya and Mekker [2]							*	
Zhu, Jiang, and Yamamoto [149]			*				*	
Jou et al. [59]								*
Adler [3]						*		
Măirean and Diaconu-Gherasim [82]								*
Weng and Meng [142]	*	*						*
Charlton and Starkey [16]						*		
Strawderman, Huang, and Garrison [121]						*		
Jung and Bell [60]				*			*	
Kim et al. [64]							*	*
Ciscal-Terry et al. [22]							*	
Brookhuis and Dicke [12]						*		
Ringhand and Vollrath [111]						*		*
Koller-Matschke, Belzner, and Glas [68]						*	*	*
Uang and Hwang [133]						*		*
Munion et al. [90]							*	
Steinbakk et al. [120]								*
SWOV [126]	*							
Vignali et al. [137]							*	
Taubman-Ben-Ari, Mikulincer, and Gillath [130]								*
Sagberg et al. [115]	*	*						
Rong, Mao, and Ma [114]					*	*		
Sun et al. [124]						*		
Xing et al. [146]					*	*		
Liu et al. [78]							*	
Qi et al. [101]				*				
Huysduynen et al. [54]								*
Eboli, Mazzulla, and Pungillo [33]								*
Johnson and Trivedi [58]							*	
Taubman-Ben-Ari and Yehiel [129]								*
Miller and Taubman-Ben-Ari [86]								*
Chen and Chen [20]								*
Herrero-Fernández [48]								*

Table 58: Methods used in previous studies

Appendix B MDSI Framework

Figure 76: MDSI framework
by Taubman-Ben-Ari, Mikulincer, and Gillath [130] and Huysduynen et al. [54]

Appendix C Brainstorm session

C.1 Driver profiles

Brainstorm questions:

- What different types of road users are there, and how might their needs and behaviours differ?
- Which road users can you see around the detour announcement and the detour itself?

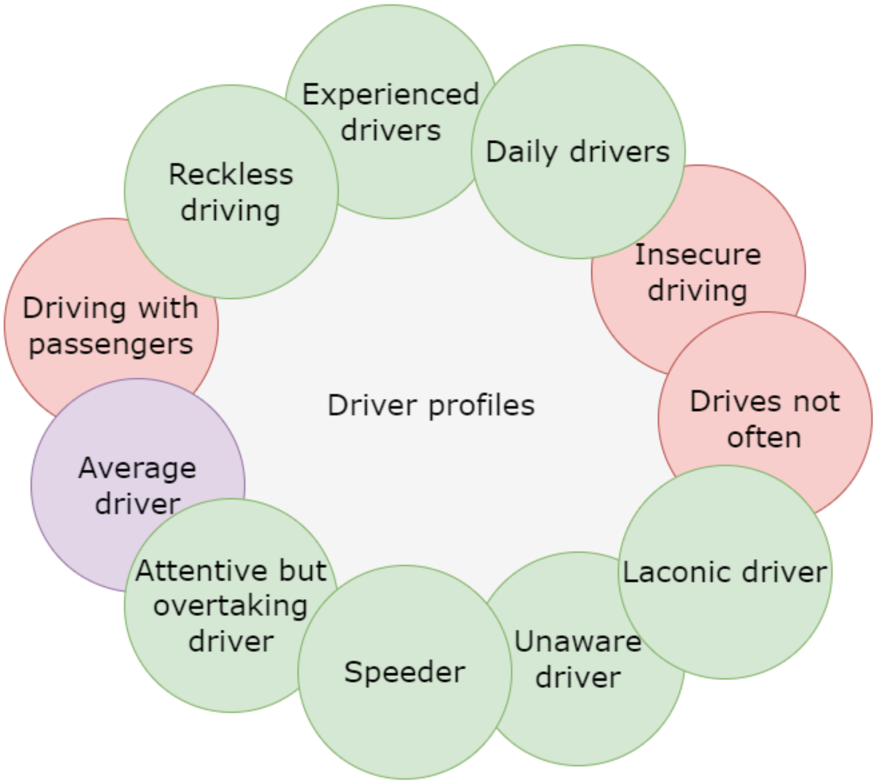


Figure 77: Driver profiles brainstorm session.

Green: higher avg. speed
Red: Lower avg.speed
Purple: Avg. speed around speed limit

C.2 Factors

Brainstorm questions:

- What factors influence driver behaviour?
- What are the factors influencing the decision to follow a detour?

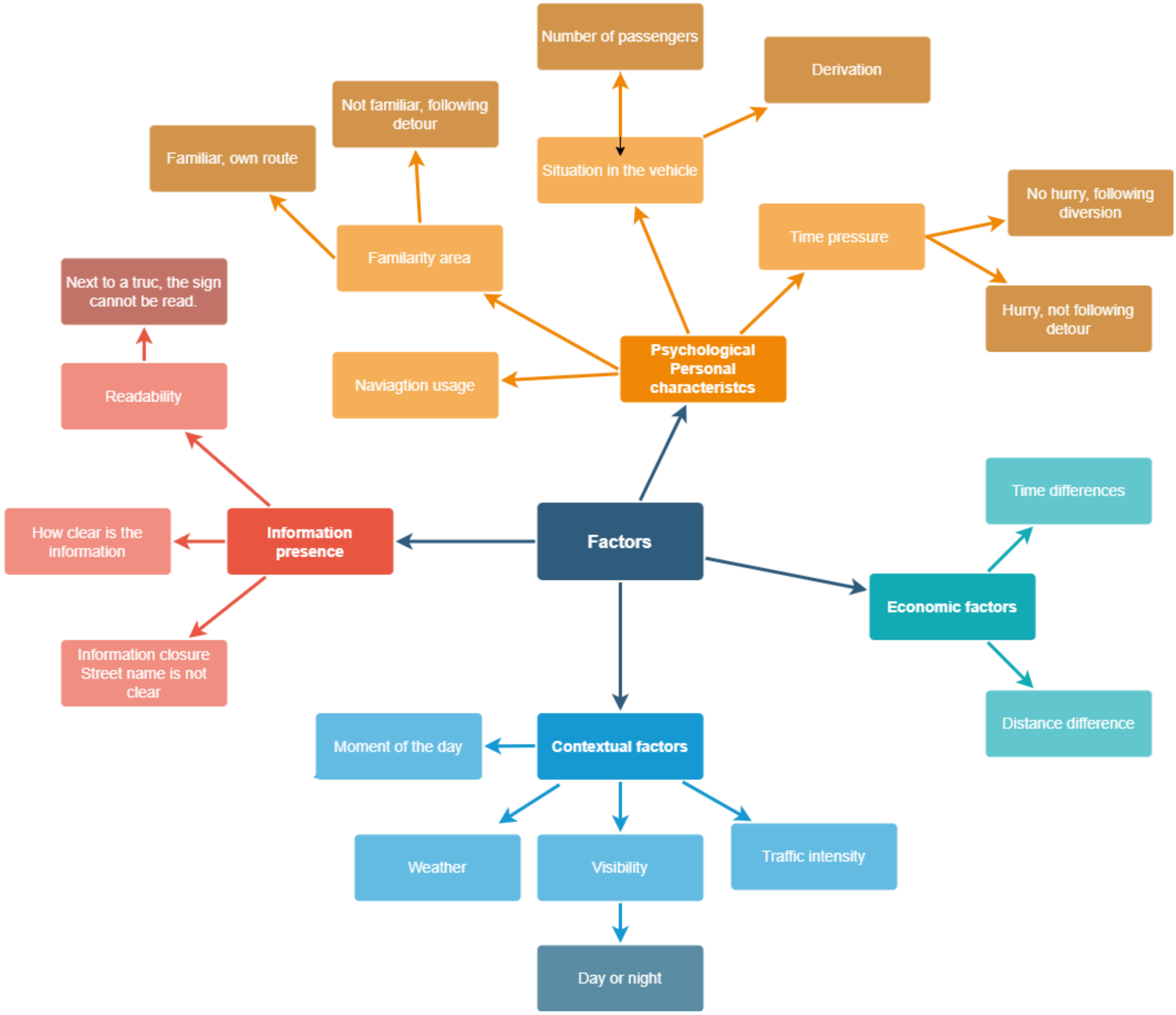


Figure 78: Factors brainstorm session

C.2.1 Driver decisions

Brainstorm questions:

- What is the road user's reaction to the situation and to traffic measures and announcements?
- What scenarios could occur at the location?

Points of impact:

- Where is the diversion located?
- How far in advance is the diversion announced?
- Are there any visible roadworks?
- Depending on the date and time visible on the announcement

Drivers reactions:

- Braking
  - Realising too late that there was something there
  - Seeing something but not knowing what
  - Wondering if it was for them
- Changing lanes
- Doubting and doing nothing as a result
- Not knowing whether that bothers me or not, is it today or any other time
- Before the start of the diversion, already figured out another route and did not have to deal with the diversion.
- Navigation says something else
- Follow navigation blindly
- Assuming your navigation does give the correct route
- Driving faster to make up extra time

C.3 A27 Case Study

Main scenarios:

- If you are unfamiliar rather detour
- Take the exit and then, seeing that it is not possible to do so, take the roundabout and return to the motorway.
- Tried to take the Afrit, saw yellow signs, then turned back after seeing the closure.
- Takes the exit and takes another detour.

Motorway section 1:
Main scenario: Traffic behaviour remains unchanged because the driver is focused on steering through the turn. If there is a change then a decrease in speed.

Motorway section 2:
Main scenario: no changes

- Possibly speed change if there is a lot of truck traffic.
- They can take the A4 if they have seen the pre-announcement.
- Briefly braking to read signs

Motorway section 3:

Main scenario: no significant differences from box 2.

There is a perception that route gauges do little. Route polls take little effort to read. However, when they are not there, it is not known what to do.

Motorway section 4:

Main scenario: Lower speed due to the dilemma of whether or not to follow the diversion.

- Doubt can I take the exit or not
- The announcement is noticed but could not remember exactly what it said, so lower speed to think longer.
- Last-minute decision

Road closure area:

- Stopping at the roundabout
- hesitating and therefore braking
- Seeing if there really is no way to pass
- Returning onto the motorway
- Just drive through hoping navigation gives something else
- People who had seen it anyway remembered it and realised they couldn't go through it after looking and turning around
- Ghost driving
- Removing closure anyway and just driving on.

Motorway section 5:

- Speed decreases: have to pay attention to how to drive now anyway
- Speed increases: have to add extra speed to avoid losing too much time
- Sticking to the right so that I take the exit anyway
- Uncertain

Appendix D Source information factors

Factors	Brainstorm	Literature	Expert Communication
Social-demographic	x	x	
Time perception		x	x
Time pressure	x	x	x
Familarity area	x	x	x
Use of navigation	x	x	x
Situation awareness	x	x	
Emotional state	x	x	
Vehicle characteristics	x		x
Social distraction	x		x
Road conditions		x	
Weather conditions	x	x	x
Light conditions	x	x	
Speed limit		x	
Construction activity status	x	x	x
Traffic congestion		x	x
Time of the day	x	x	
Number of lanes	x	x	
Time differences	x	x	x
Extra costs			x
Distance differences	x	x	x

Table 59: Source of information factors

Appendix E Driving patterns road closure area

Motorway section partial closure
Scenario 13: Not all lanes are closed, and therefore the road user can get around the road works.

The lane capacity in scenario 13 is lower than normal. This section of the motorway has a lower capacity, so if it is used by a high volume of traffic, safety or traffic flow may be affected, and therefore this possibility was not announced earlier. It may be that drivers knew this was a possibility because they were aware of the circumstances.

Motorway section closure
Scenario 14: Road users are forced to turn around using the exit ramp at the location of the motorway closure.

The road user cannot continue on the motorway as it is completely closed. Therefore, the road user is forced to take the exit and find another route to continue their journey. The road user could find another route to reach their destination or turn at the exit to rejoin the motorway in the opposite direction.

Secondary road network road closure
Scenario 15: Drivers choose an alternative route available at the location of the closure.

In this scenario, the exit is available to traffic from the motorway in the direction of the closed road. The closed road is located shortly after the exit ramp, preventing traffic from continuing in that direction. In some cases, there is an alternative route available for drivers to take at the closure point. The reason this possible shortcut is not shown in more detail previously is that the road in question has a lower capacity, which means that using it extensively could affect the safety or flow of traffic. The road users in question may have been aware of the circumstances and therefore knew that this was a possibility.

Scenario 16: The road users will have to turn around at the place of the closure in order to return to the motorway or to an alternative route.

In this situation, after taking the exit, there is no available route for the road user to continue in the preferred direction. Therefore, the road user is forced to return to the motorway to turn around at the next exit or to find another route.

Exit ramp partial road closure
Scenario 17: Not all exit ramp lanes are closed, and therefore the road user can get around the road works.

In this case, the capacity of the exit ramp is smaller than in normal circumstances. Similar to scenario 16, there are reasons why the possibility of using the exit was not announced earlier: this route has a smaller capacity, so if it is used frequently, it may affect safety or traffic flow. As in scenario 16, it may be that drivers knew this was a possibility because they were aware of the circumstances.

Exit ramp road closure
Scenario 18: The exit ramp is closed and road users must continue driving to turn around at the next exit.

In scenario 18, the road user is unable to take the exit due to the closure. Therefore, they have to continue to the next exit to turn around or find another route.

Appendix F   Traffic measurements A9 exit Aalsmeer

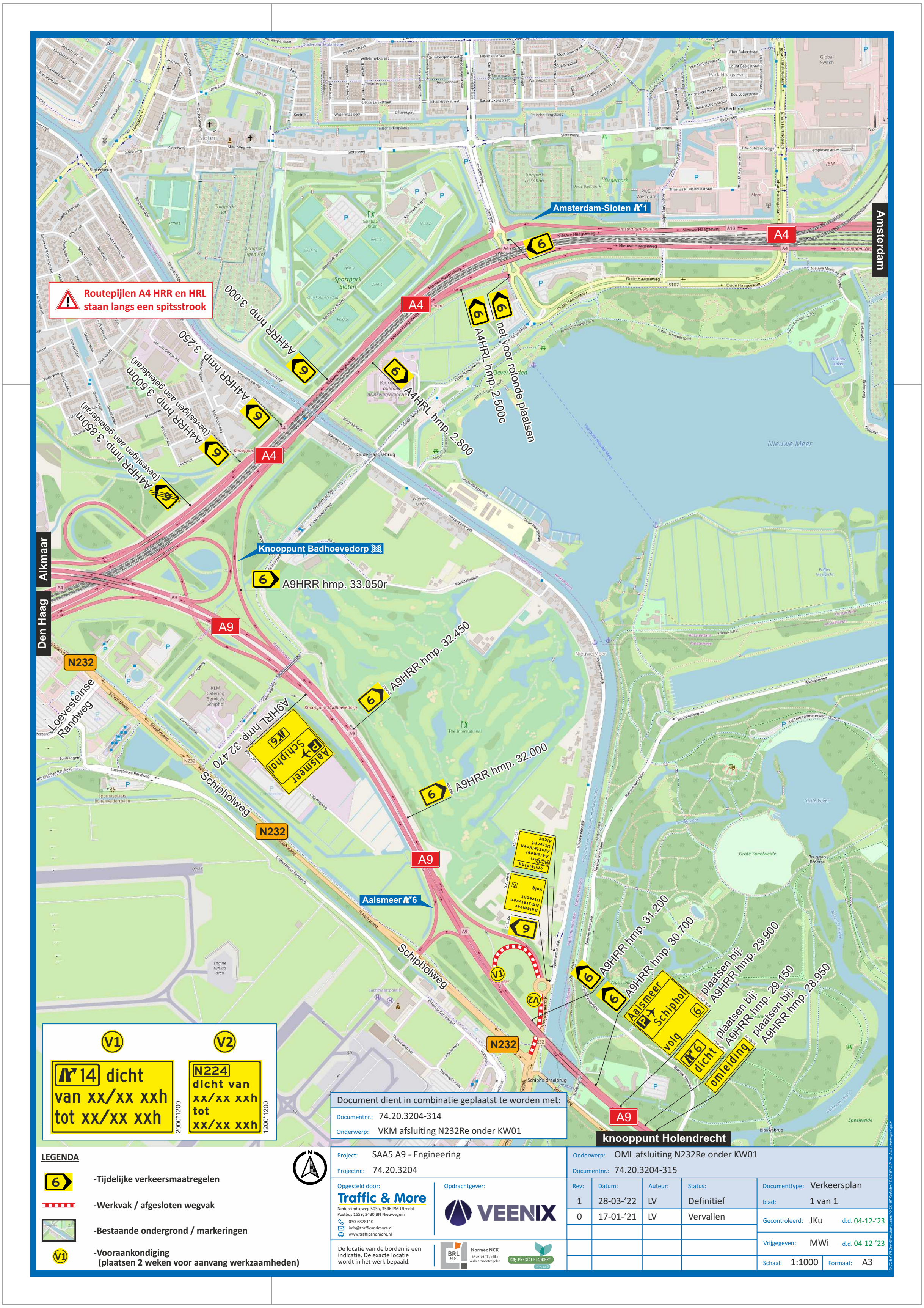


Figure 79: Traffic measurements test case study A9 exit Aalsmeer

Appendix G Road closure Schipholweg

G.1 Closure Schipholweg alternative routes

Figure 80: Alternative route Badhoevedorp

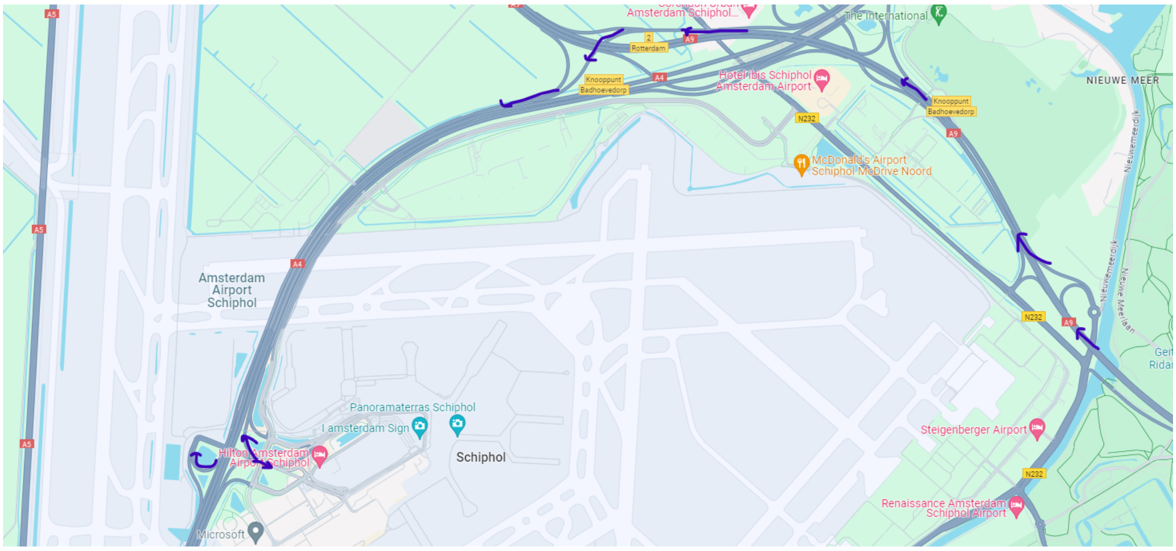


Figure 81: Alternative route Schiphol

G.2 Closure Schipholweg extra time

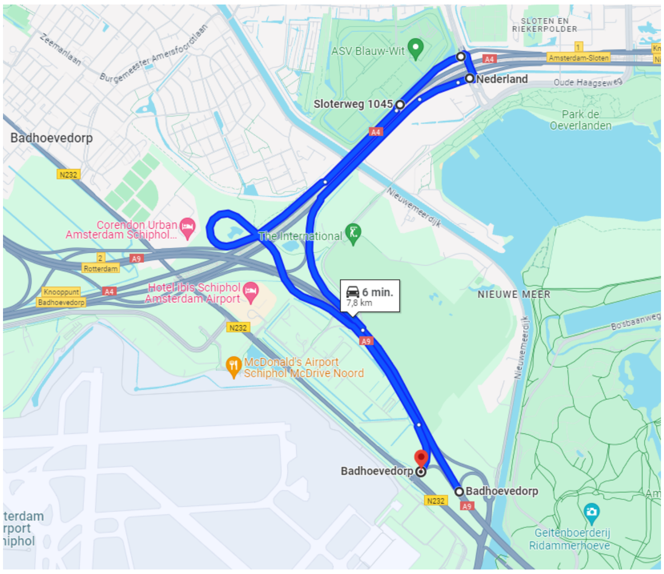


Figure 82: Extra journey time diversion conducted on 19-02-2023 at 10h11 [42]

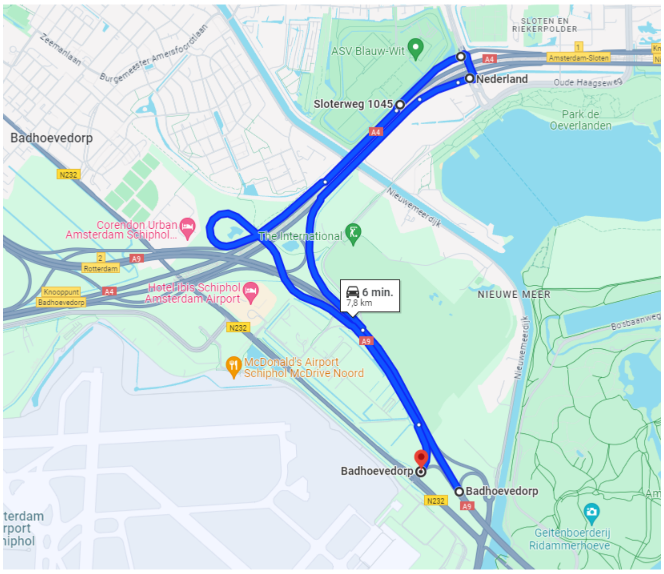


Figure 83: Extra journey time diversion case study conducted on 19-02-2023 at 10h21 [42]

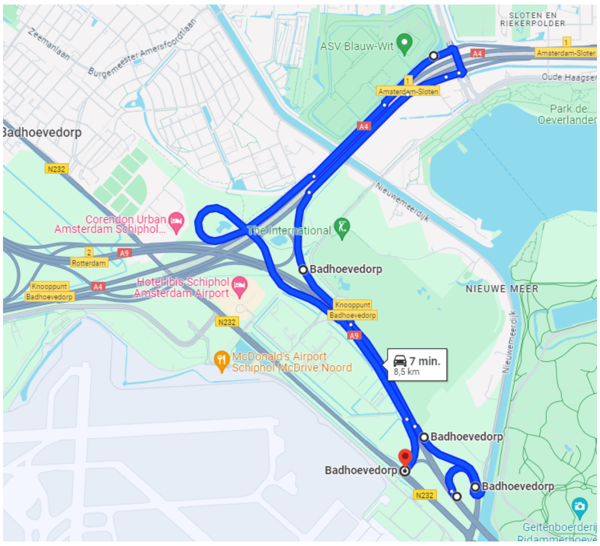


Figure 84: Extra journey time diversion including taking the exit case study conducted on 19-02-2023 at 10h21 [44]

Appendix H Measurement values A9 case study

H.1 Average traffic volumes A9

Table 60: Average traffic volumes closure phase A9

Closure phase Average Traffic Volumes values A9											
Day		**Tuesday**					**Thursday**				
Time	**HMP**	**Mean 2022**	**Mean 2023**	**Mean 2024**	**Min 2024**	**Max 2024**	**Mean 2022**	**Mean 2023**	**Mean 2024**	**Min 2024**	**Max 2024**
22-23	**30.8**	976.4	1116.2	1068.4	817	1197	1149.9	1407.9	1310	1036	1504
	31.2	873.6	1023.5	1064.7	786	1218	1059.8	1300.5	1314.5	1055	1523
	31.6	828.2	972.8	955.9	679	1094	999.2	1232.2	1175.7	924	1423
	32.0	1194.4	1316.4	1272.6	1089	1474	1395.9	1576.4	1576.5	1392	1744
23-24	**30.8**	758.5	699.6	658	577	873	724.6	-	853.2	734	1135
	31.2	711.5	663.9	648.7	521	881	688.4	941.2	860.8	743	1170
	31.6	684.7	625.9	612.7	522	809	652.2	884.3	787.8	672	1085
	32.0	993.9	909.7	885.4	744	1217	972.5	1181.3	1125	1030	1222
24-01	**30.8**	335.8	338.5	294	268	318	317	-	408.7	359	463
	31.2	315.2	320.1	260.3	83	321	295.5	424.9	419.2	366	483
	31.6	295.9	297.4	263.6	240	298	285	397	369.3	315	428
	32.0	399.9	401.3	362	299	429	397.5	515.9	520	470	625
01-02	**30.8**	158.5	175.7	180.1	160	229	172.5	-	201	174	217
	31.2	140.8	160.2	161	-	208	154	192.1	211	176	241
	31.6	120.2	143	159.9	136	199	137.5	171.9	172.8	150	202
	32.0	179.5	214.2	211.3	165	257	202.5	242.5	258.2	232	295
02-03	**30.8**	132.3	141.2	132.3	116	156	141.5	-	145.3	126	175
	31.2	110.5	123.7	119.3	-	164	118	150.2	151.8	131	191
	31.6	95.9	101.4	102.6	79	134	105	123.4	112.8	93	145
	32.0	133.2	147.8	152.1	129	175	150.5	169.8	174.5	159	191
03-04	**30.8**	205.9	264.2	227.3	213	246	230.5	-	270.8	254	305
	31.2	153.2	204.7	200.4	-	263	175.5	239.3	281.5	266	313
	31.6	120	152.6	153.4	130	245	137.5	170.3	161.8	141	200
	32.0	152.4	189.9	201	159	260	177	219.7	216.2	192	233

H.2 Traffic volumes A9

Table 61: Traffic volumes closure Phase A9

Closure phase Traffic Volumes values A9										
Day		**Tuesday**				**Thursday**				
Time	**HMP**	**6-7 Feb**	**Mean**	**Min**	**Max**	**1-2 Feb**	**8 -9 Feb**	**Mean**	**Min**	**Max**
22-23	**30.8**	1155	1068.4	817	1197	1358	1504	1310	1036	1504
	31.2	1198	1064.7	786	1218	1344	1523	1314.5	1055	1523
	31.6	1074	955.9	679	1094	1193	1423	1175.7	924	1423
	32.0	1235	1272.6	1089	1474	1715	1566	1576.5	1392	1744
23-24	**30.8**	716	658	577	873	843	1135	853.2	734	1135
	31.2	738	648.7	521	881	840	1170	860.8	743	1170
	31.6	682	612.7	522	809	770	1085	787.8	672	1085
	32.0	766	885.4	744	1217	1222	1183	1125	1030	1222
24-01	**30.8**	283	294	268	318	463	427	408.7	359	463
	31.2	83	260.3	83	321	483	459	419.2	366	483
	31.6	268	263.6	240	298	428	406	369.3	315	428
	32.0	299	362	299	429	625	470	520	470	625
01-02	**30.8**	165	180.1	160	229	174	201	201	174	217
	31.2	-	161	-	208	176	241	211	176	241
	31.6	153	159.9	136	199	150	202	172.8	150	202
	32.0	165	211.3	165	257	266	232	258.2	232	295
02-03	**30.8**	129	132.3	116	156	126	175	145.3	126	175
	31.2	-	119.3	-	164	131	191	151.8	131	191
	31.6	110	102.6	79	134	109	145	112.8	93	145
	32.0	130	152.1	129	175	166	168	174.5	159	191
03-04	**30.8**	231	227.3	213	246	254	305	270.8	254	305
	31.2	-	200.4	-	263	267	313	281.5	266	313
	31.6	174	153.4	130	245	141	200	161.8	141	200
	32.0	241	201	159	260	208	231	216.2	192	233

H.3 Average speed over the years A9

Table 62: Average speed closure phase A9

Closure phase Average speed years values A9											
Day		**Tuesday**					**Thursday**				
Time	**HMP**	**Mean 2022**	**Mean 2023**	**Mean 2024**	**Min 2024**	**Max 2024**	**Mean 2022**	**Mean 2023**	**Mean 2024**	**Min 2024**	**Max 2024**
22-23	**30.8**	106.3	106.2	99.0	81.3	105.9	105.2	104.8	103.2	82.6	110.3
	31.2	106.8	105.3	93.5	76.8	101.8	104.3	103.6	97.9	78.9	102.8
	31.6	109.8	109.6	100.4	85.2	107.9	107.3	108.3	103.1	85.2	107.8
	32.0	104.3	104.9	99.8	92.1	103.8	102.9	104.1	102.1	100.1	103.3
23-24	**30.8**	106.8	106.8	101.5	85.8	109.3	105.8	103.7	104.2	84.2	111.1
	31.2	108.1	104.7	97.7	81.9	106.8	105.5	101.9	99.5	81.1	105.1
	31.6	111.4	109.5	103.4	88.4	106.8	108.6	107.5	104.4	86.9	109.1
	32.0	105.4	104.9	100.9	94.9	104.1	103.1	102.8	101.8	98	103.9
24-01	**30.8**	104.9	106.4	99.9	88.5	106.9	108.1	105.2	100.64	79.7	112.5
	31.2	108.4	103.8	92.1	81.4	100.1	107.8	103.6	99.3	85.2	105.7
	31.6	111.2	108.7	99.9	90.2	107.9	110.6	106.9	102.7	90.5	109.8
	32.0	105.4	103.8	99.6	94.6	104.8	103.8	103.6	97.3	84.2	103.7
01-02	**30.8**	101.8	103.3	100.9	82.6	123.9	103.2	102.7	99.8	86.0	108.7
	31.2	101.6	98.7	92.9	81.2	110.8	103.4	101.7	95.9	86.4	105.8
	31.6	106.8	105.4	99.5	91.4	107.9	106.5	106.1	101.9	90.7	112.6
	32.0	100.5	99.3	96.4	90.6	103.9	101.6	102.6	98.8	90.9	104.8
02-03	**30.8**	100.4	101.9	95.9	84.4	104.6	99.7	99.9	97.3	85.8	102.7
	31.2	98.6	98.4	90.8	87.4	97.7	100.2	97.9	91.0	77.4	96.9
	31.6	102	103.3	99.8	85.5	114	102.8	103.3	101.1	92.9	107.0
	32.0	97.2	98.8	97.7	90.7	107.2	99.9	97.7	92.3	73.8	97.8
03-04	**30.8**	101.8	104.9	98.6	85.2	111.7	101.5	105.7	102.9	95.3	107.1
	31.2	98.8	96.9	95.3	83.8	104.5	96.7	98.9	95.8	91.7	102.8
	31.6	102.3	102.9	98.8	88.3	104.3	101.7	103.9	99.6	93.2	102.8
	32.0	99.0	94.4	98.4	90.5	112.6	96.3	98.7	98.6	87.2	105.9

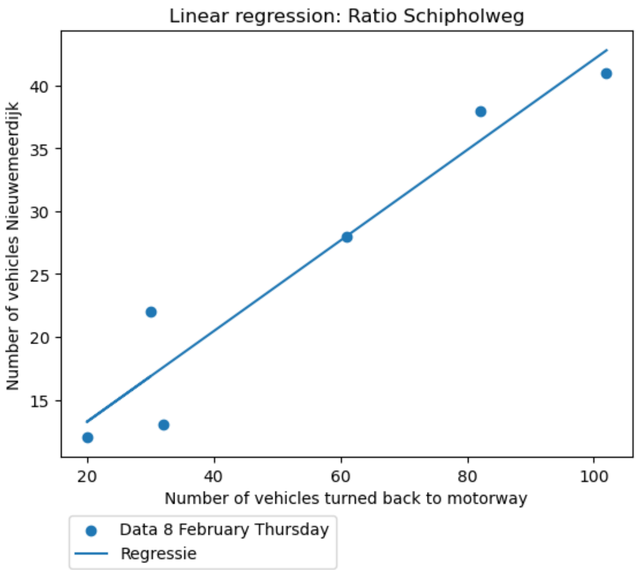
H.4 Average speed closure phase A9

Table 63: Average speed closure Phase A9

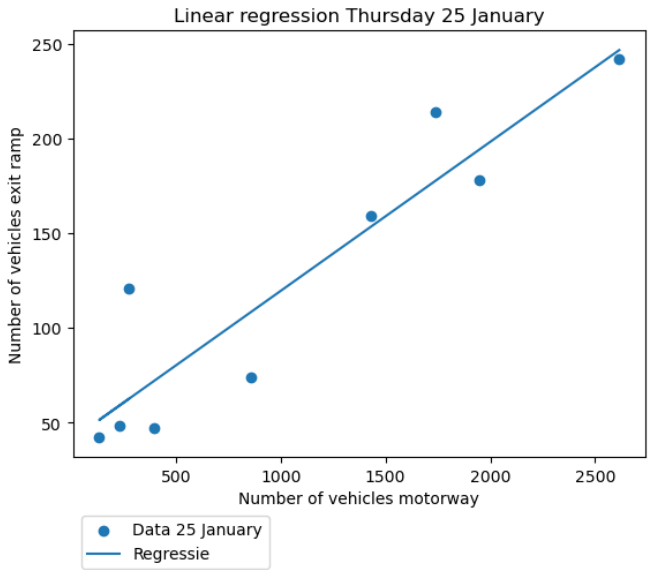
Closure phase average speed values A9										
Day		**Tuesday**				**Thursday**				
Time	**HMP**	**6-7 Feb**	**Mean**	**Min**	**Max**	**1-2 Feb**	**8 -9 Feb**	**Mean**	**Min**	**Max**
22-23	**30.8**	81.3	99.0	81.3	105.9	105.3	82.6	103.2	82.6	110.3
	31.2	76.8	93.5	76.8	101.8	102.6	78.9	97.9	78.9	102.8
	31.6	85.2	100.4	85.2	107.9	106.4	85.2	103.1	85.2	107.8
	32.0	92.1	99.8	92.1	103.8	103.3	100.1	102.1	100.1	103.3
23-24	**30.8**	85.8	101.5	85.8	109.3	107.7	84.2	104.2	84.2	111.1
	31.2	81.9	97.7	81.9	106.8	104.5	81.1	99.5	81.1	105.1
	31.6	88.4	103.4	88.4	106.8	107.4	86.9	104.4	86.9	109.1
	32.0	94.9	100.9	94.9	104.1	103.9	98	101.8	98	103.9
24-01	**30.8**	88.5	99.9	88.5	106.9	110.4	85.8	100.64	79.7	112.5
	31.2	81.4	92.1	81.4	100.1	105.7	85.2	99.3	85.2	105.7
	31.6	91.9	99.9	90.2	107.9	109.8	90.5	102.7	90.5	109.8
	32.0	94.6	99.6	94.6	104.8	103.7	95.1	97.3	84.2	103.7
01-02	**30.8**	82.6	100.9	82.6	123.9	103.6	86.0	99.8	86.0	108.7
	31.2	-	92.9	81.2	110.8	104.4	86.4	95.9	86.4	105.8
	31.6	94.3	99.5	91.4	107.9	112.6	90.7	101.9	90.7	112.6
	32.0	90.6	96.4	90.6	103.9	97.9	96.1	98.8	90.9	104.8
02-03	**30.8**	84.4	95.9	84.4	104.6	102.4	85.8	97.3	85.8	102.7
	31.2	-	90.8	87.4	97.7	96.5	86.7	91.0	77.4	96.9
	31.6	94.5	99.8	85.5	114	105.1	93.8	101.1	92.9	107.0
	32.0	97.1	97.7	90.7	107.2	97.1	92.2	92.3	73.8	97.8
03-04	**30.8**	86.9	98.6	85.2	111.7	100.5	95.3	102.9	95.3	107.1
	31.2	-	95.3	83.8	104.5	92.8	93	95.8	91.7	102.8
	31.6	94.2	98.8	88.3	104.3	99.5	99.5	99.6	93.2	102.8
	32.0	90.5	98.4	90.5	112.6	95.3	100.8	98.6	87.2	105.9

Appendix I Linear regression Method

I.1 Linear regression plots A9

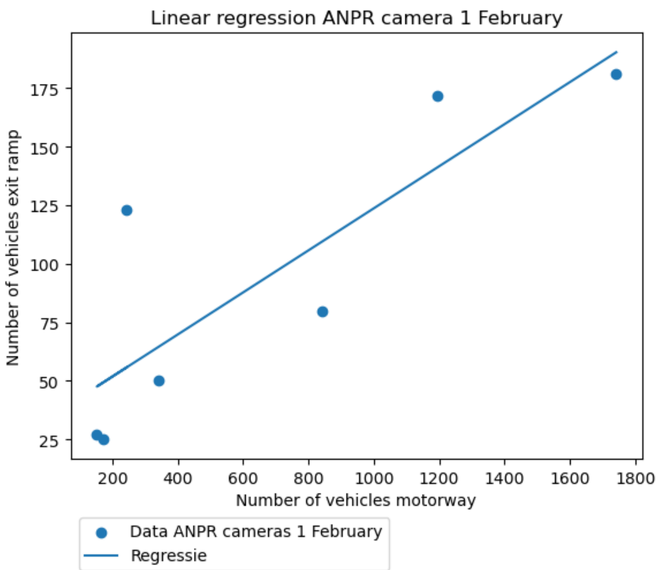


(a) Linear regression Schipholweg ratio

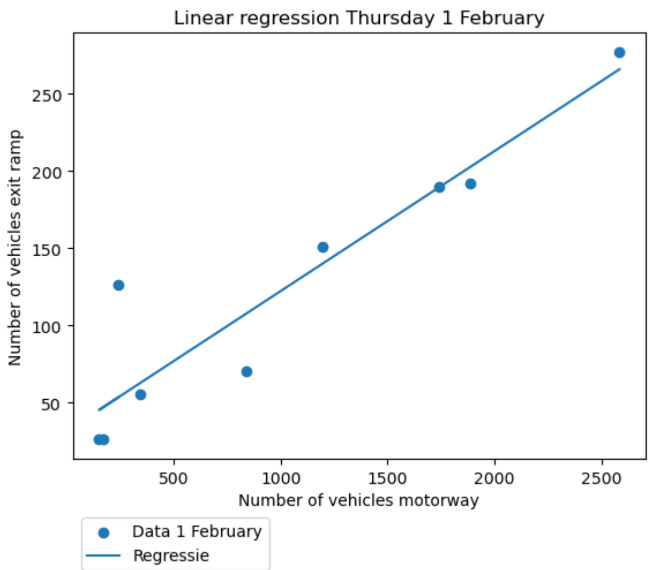


(b) Linear Regression 25 January

Figure 85: Linear regression approaches

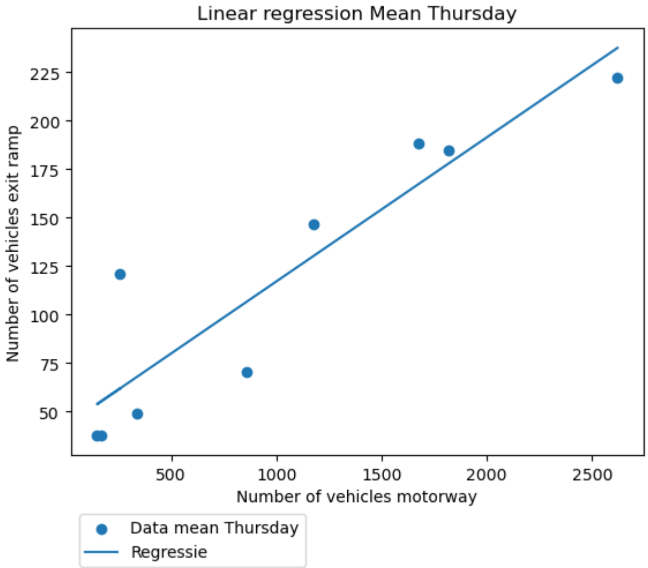


(a) Linear regression 1 Feb ANPR cameras

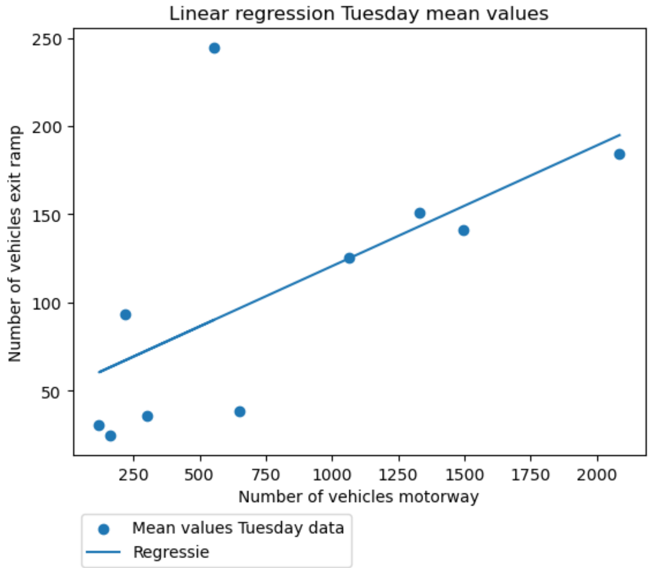


(b) Linear Regression 1 February NDW data

Figure 86: Linear regression 1 February approaches

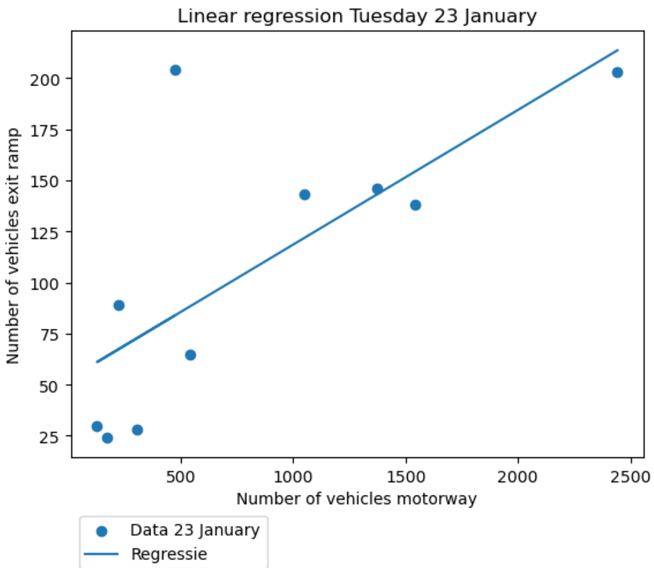


(a) Mean values Thursday 2024

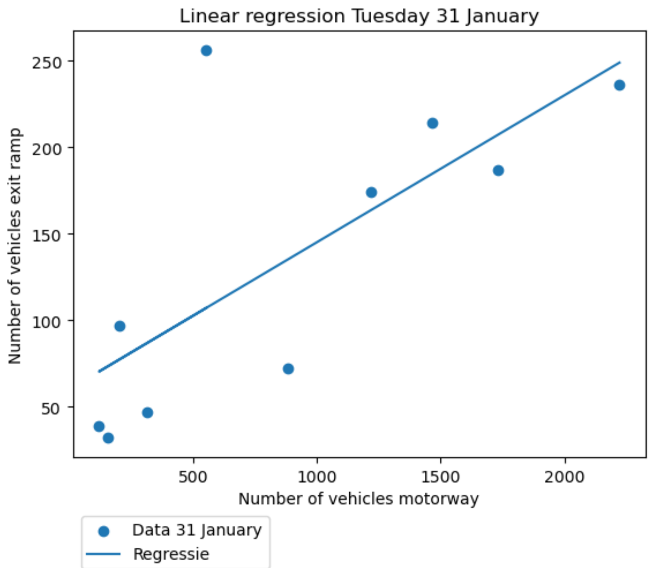


(b) Mean values Tuesday 2024

Figure 87: Linear regression mean value approaches



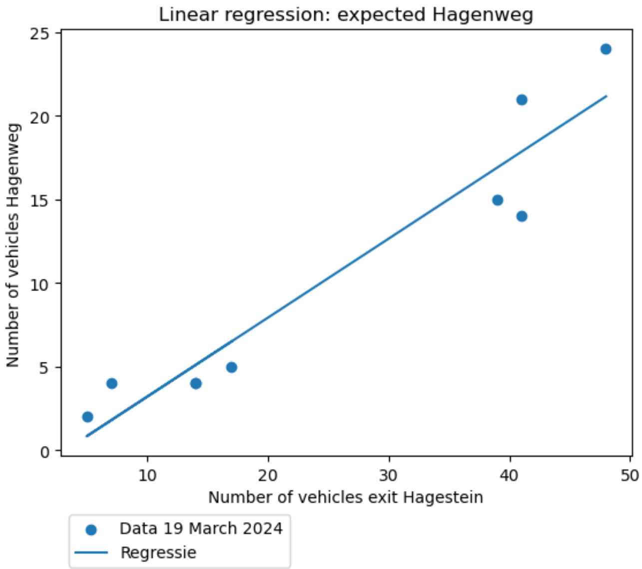
(a) Tuesday 23 January



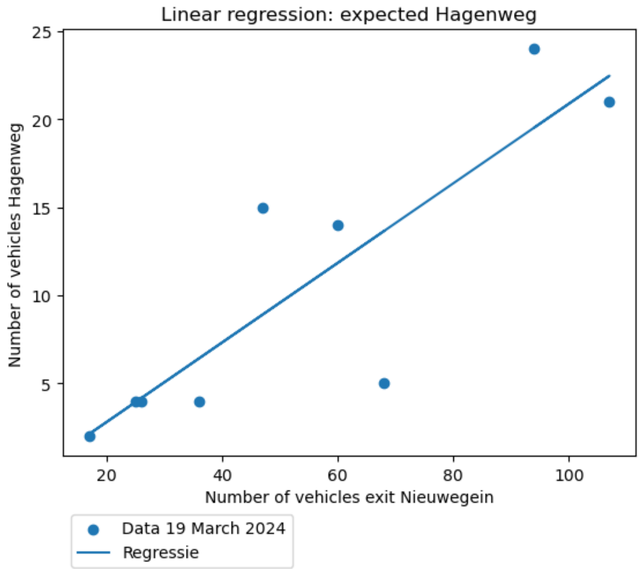
(b) Tuesday 31 January

Figure 88: Linear regression Tuesday approaches

I.2 Linear regression plots A27



(a) Linear regression exit Hagestein



(b) Linear regression exit Nieuwegein

Figure 89: Linear regression Hagenweg

Appendix J Traffic measurements A27 exit Hagestein

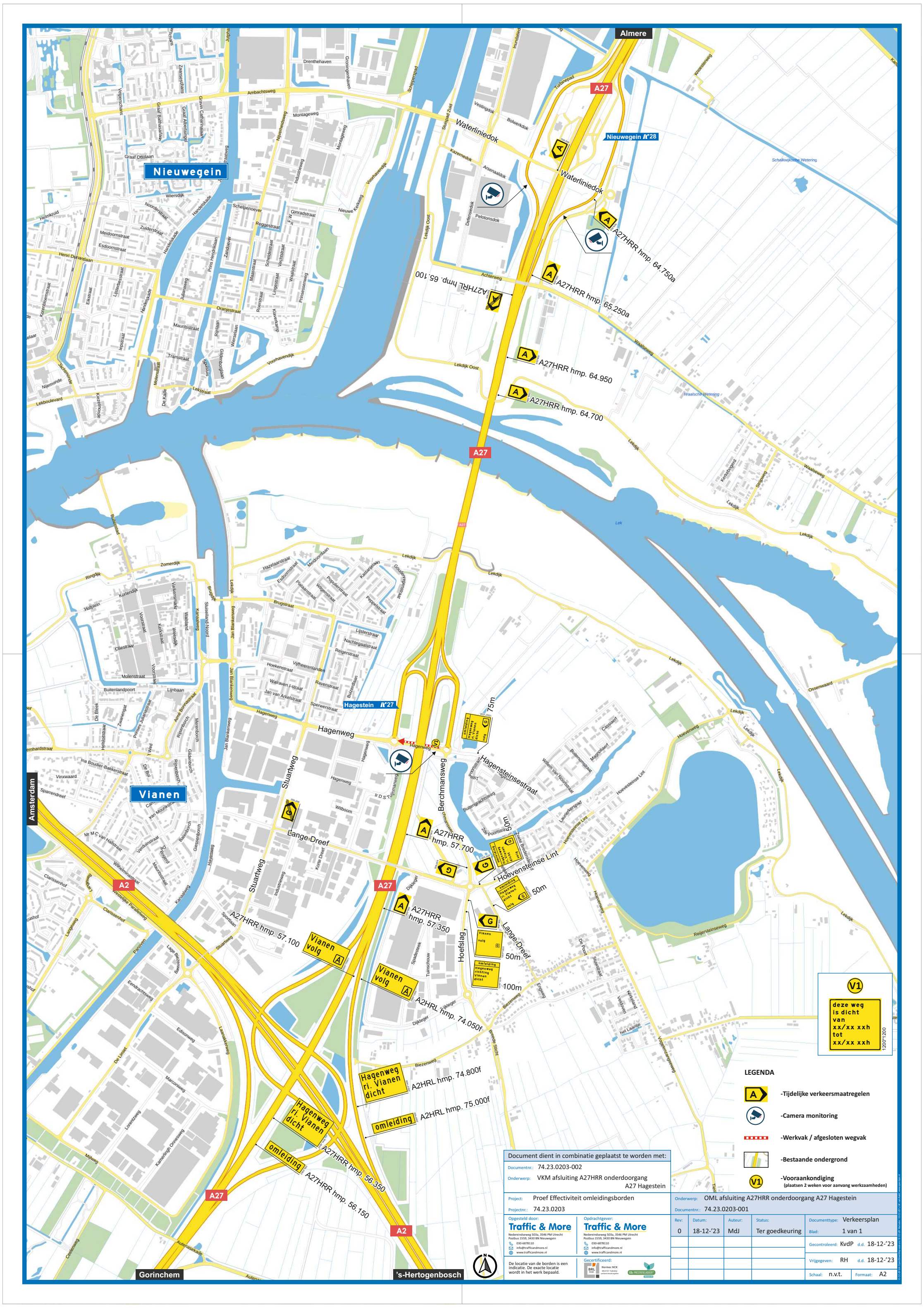


Figure 90: Traffic measurements case study A27 exit Hagestein

Appendix K Measurement values A27 Case study

K.1 ANPR camera measurements

Table 64: ANPR camera measurements A27 27-28 February

ANPR cameras 27-28 Feb A27									
Time	**20-21**	**21-22**	**22-23**	**23-24**	**24 01**	**01 02**	**02 03**	**03 04**	**04 05**
Exit Hagestein	43	47	35	33	11	6	2	12	15
Exit Hagestein to Lange Dreef	0	16	12	9	5	1	0	4	3
Exit Hagestein to Access Nieuwegein	0	2	1	0	0	0	0	1	0
Exit Hagestein to Exit Nieuwegein	0	3	1	2	0	0	0	1	0
Exit Nieuwegein	126	99	109	71	40	26	21	30	74
Exit Nieuwegein to Access Nieuwegein	5	9	10	3	3	1	1	3	1
Exit Nieuwegein to Exit Nieuwegein	1	1	0	0	0	0	0	0	0
Lange Dreef	75	117	69	43	61	20	14	18	22
Lange Dreef to Access Nieuwegein	1	0	0	0	0	0	0	0	0
Lange Dreef to Exit Nieuwegein	1	0	0	0	0	0	0	0	0
Access Nieuwegein	183	142	107	86	51	31	26	49	46
Access Nieuwegein to Exit Nieuwegein	3	1	0	0	0	0	0	0	0
Access Nieuwegein to Access Nieuwegein	0	1	0	0	0	0	0	0	0
Access Nieuwegein to Langedreef	0	1	0	0	0	1	0	0	0

Table 65: ANPR camera measurements A27 5-6 March

ANPR cameras 5-6 March A27									
Time	**20-21**	**21-22**	**22-23**	**23-24**	**24 01**	**01 02**	**02 03**	**03 04**	**04 05**
Exit Hagestein	53	42	34	35	16	10	7	15	15
Exit Hagestein to Lange Dreef	1	0	1	0	0	0	1	1	0
Exit Hagestein to Access Nieuwegein	0	0	0	0	0	0	0	0	0
Exit Hagestein to Exit Nieuwegein	0	0	0	0	0	0	0	0	0
Exit Nieuwegein	117	87	83	61	31	26	18	33	68
Exit Nieuwegein to Access Nieuwegein	4	0	2	1	1	0	0	1	0
Exit Nieuwegein to Exit Nieuwegein	0	0	0	0	0	0	0	0	0
Lange Dreef	90	37	26	13	30	39	11	16	17
Lange Dreef to Access Nieuwegein	0	0	0	0	0	0	0	0	0
Lange Dreef to Exit Nieuwegein	0	0	0	0	0	0	0	0	0
Access Nieuwegein	163	148	108	79	59	29	35	25	51
Access Nieuwegein to Exit Nieuwegein	1	1	0	0	0	0	0	0	0
Access Nieuwegein to Access Nieuwegein	0	0	0	0	0	0	0	0	0
Access Nieuwegein to Langedreef	0	0	0	0	0	0	0	0	0

Table 66: ANPR camera measurements A27 12-13 March

ANPR cameras 12-13 March A27									
Time	**20-21**	**21-22**	**22-23**	**23-24**	**24 01**	**01 02**	**02 03**	**03 04**	**04 05**
Exit Hagestein	51	57	59	37	16	12	4	9	23
Exit Hagestein to Lange Dreef	0	16	21	7	7	5	1	2	6
Exit Hagestein to Access Nieuwegein	0	5	7	0	1	1	0	0	0
Exit Hagestein to Exit Nieuwegein	0	1	1	0	1	1	0	0	0
Exit Nieuwegein	132	126	118	75	40	31	17	28	70
Exit Nieuwegein to Access Nieuwegein	2	11	8	2	9	3	1	1	0
Exit Nieuwegein to Exit Nieuwegein	0	0	0	0	0	0	0	0	0
Lange Dreef	87	100	58	37	43	49	14	15	31
Lange Dreef to Access Nieuwegein	0	0	0	0	0	0	0	0	0
Lange Dreef to Exit Nieuwegein	0	0	0	0	0	1	0	0	0
Access Nieuwegein	191	194	113	77	58	39	24	50	41
Access Nieuwegein to Exit Nieuwegein	1	0	0	1	0	0	0	0	0
Access Nieuwegein to Access Nieuwegein	0	0	0	0	0	0	0	0	0
Access Nieuwegein to Langedreef	2	0	0	0	0	0	0	0	0

Table 67: ANPR camera measurements A27 19-20 March

ANPR cameras 5-6 March A27									
Time	**20-21**	**21-22**	**22-23**	**23-24**	**24 01**	**01 02**	**02 03**	**03 04**	**04 05**
Exit Hagestein	48	41	41	39	14	7	5	14	17
Exit Hagestein to Hagenweg	24	21	14	15	4	4	2	4	5
Exit Hagestein to Access Nieuwegein	0	0	1	0	0	0	0	0	0
Exit Hagestein to Exit Nieuwegein	0	0	0	0	0	0	0	0	0
Exit Nieuwegein	94	107	60	47	36	26	17	25	68
Exit Nieuwegein to Access Nieuwegein	3	6	1	2	0	0	0	1	0
Exit Nieuwegein to Exit Nieuwegein	0	0	0	0	0	0	0	0	0
Hagenweg	106	83	151	69	12	13	4	9	16
Hagenweg to Hagenweg	0	0	10	3	0	0	0	0	0
Hagenweg to Exit Nieuwegein	0	0	0	0	0	0	0	0	0
Access Nieuwegein	169	141	119	60	44	33	26	43	42
Access Nieuwegein to Exit Nieuwegein	1	2	0	0	0	0	0	0	0
Access Nieuwegein to Access Nieuwegein	0	0	0	0	0	0	0	0	0
Access Nieuwegein to Hagenweg	1	2	1	0	0	0	0	0	0

K.2 Average traffic volumes A27

Table 68: Mean Traffic volumes closure phase A27

Mean traffic volumes A27 closure phase													
Section		**1**			**2**		**3**	**4**			**5**		
Time	**HMP**	**74.1**	**74.5**	**74.8**	**56.2**	**57.0**	**57.7**	**58.1**	**58.4**	**58.9**	**124.4**	**124.9**	**65.4**
22-23	**Mean 2022**	403.0	405.9	417.7	440.7	433.6	868.8	863.8	812.2	944.8	933.8	851.8	836.0
	Mean 2023	457.9	449.6	464.1	470.6	459.6	955.6	945.6	891.8	1041.6	-	-	922.8
	Mean 2024	451.1	458.0	467.8	423.9	426.6	903.8	901.9	851.0	981.4	956.6	868.7	853.7
	Min 2024	334.0	343.0	343.0	131.0	133.0	781.0	795.0	747.0	771.0	703.0	746.0	609.0
	Max 2024	705.0	686.0	713.0	654.0	658.0	1096.0	1098.0	1196.0	1196.0	1173.0	1044.0	1033.0

Table 68: Mean Traffic volumes closure phase A27

Mean traffic volumes A27 closure phase													
Section		**1**			**2**		**3**	**4**			**5**		
Time	**HMP**	**74.1**	**74.5**	**74.8**	**56.2**	**57.0**	**57.7**	**58.1**	**58.4**	**58.9**	**124.4**	**124.9**	**65.4**
23-24	**Mean 2022**	245.6	246.0	252.4	267.3	261.1	526.7	524.7	489.8	577.3	556.1	495.8	489.6
	Mean 2023	299.5	300.5	306.8	304.2	297.4	612.3	609.2	567.1	639.3	-	-	538.8
	Mean 2024	290.1	303.3	312.0	253.6	257.6	558.5	556.5	513.2	597.4	587.3	524.1	515.0
	Min 2024	214.0	232.0	233.0	69.0	70.0	460.0	457.0	423.0	509.0	502.0	436.0	434.0
	Max 2024	423.0	425.0	440.0	334.0	340.0	683.0	689.0	639.0	714.0	693.0	635.0	626.0
24-01	**Mean 2022**	117.2	116.8	118.7	155.7	152.8	277.3	276.3	258.9	292.1	306.5	271.3	265.7
	Mean 2023	144.0	142.4	146.0	177.6	175.4	325.7	326.5	333.8	366.5	-	-	306.6
	Mean 2024	144.9	156.9	162.9	146.5	145.9	301.3	299.5	277.3	327.9	322.2	285.4	281.0
	Min 2024	98.0	103.0	110.0	25.0	24.0	225.0	222.0	197.0	229.0	234.0	198.0	200.0
	Max 2024	335.0	347.0	364.0	180.0	174.0	520.0	514.0	485.0	643.0	542.0	498.0	499.0
01-02	**Mean 2022**	83.0	79.8	84.7	104.0	103.2	191.4	189.8	178.4	198.8	209.9	184.8	180.2
	Mean 2023	86.7	86.2	87.6	116.6	115.0	203.2	202.9	190.4	220.9	-	-	183.9
	Mean 2024	93.5	95.5	94.4	98.4	98.6	195.0	195.2	185.8	218.9	211.9	184.6	183.4
	Min 2024	80.0	79.0	75.0	44.0	42.0	169.0	175.0	163.0	197.0	188.0	166.0	165.0
	Max 2024	128.0	129.0	131.0	124.0	119.0	229.0	225.0	214.0	241.0	233.0	204.0	206.0
02-03	**Mean 2022**	79.3	75.3	79.0	91.6	90.3	174.0	172.7	161.6	171.1	181.7	154.6	149.8
	Mean 2023	72.9	73.7	75.1	103.3	101.4	173.2	172.3	161.1	182.6	-	-	154.3
	Mean 2024	71.4	72.5	73.6	96.7	95.7	168.9	170.0	162.0	178.6	176.9	156.6	153.6
	Min 2024	64.0	63.0	64.0	89.0	86.0	154.0	158.0	149.0	164.0	162.0	139.0	134.0
	Max 2024	83.0	84.0	84.0	104.0	104.0	189.0	190.0	178.0	193.0	198.0	170.0	167.0
03-04	**Mean 2022**	91.1	87.3	91.5	117.6	115.1	212.4	209.8	199.8	204.1	218.8	186.5	183.1
	Mean 2023	81.8	74.4	81.4	99.8	102.3	180.7	178.4	162.9	186.3	-	-	152.4
	Mean 2024	78.6	78.6	80.9	111.2	111.3	194.4	194.2	178.3	198.9	197.5	165.6	163.0
	Min 2024	68.0	70.0	74.0	85.0	83.0	161.0	161.0	146.0	174.0	172.0	137.0	136.0
	Max 2024	87	89	89	130	130	216	219	210	232	228	197	196

K.3 Traffic volumes A27

Table 69: Traffic volumes closure phase A27

Traffic volumes A27 closure phase													
Section		**1**			**2**		**3**	**4**			**5**		
Time	**HMP**	**74.1**	**74.5**	**74.8**	**56.2**	**57.0**	**57.7**	**58.1**	**58.4**	**58.9**	**124.4**	**124.9**	**65.4**
22-23	**27-28 Feb**	468	469	477	407	404	909	897	848	997	981	871	867
	12-13 March	418	408	427	654	658	1096	1098	1030	1196	1173	1044	1033
	Mean 2024	451.1	458	467.8	423.9	426.6	903.8	901.9	851	981.4	956.6	868.7	853.7
	Min 2024	334	343	343	131	133	781	795	747	771	703	746	609
	Max 2024	705	686	713	654	658	1096	1098	1196	1196	1173	1044	1033
23-24	**27-28 Feb**	329	316	333	277	279	617	615	572	662	641	569	557
	12-13 March	292	294	305	334	340	649	639	594	696	685	615	599
	Mean 2024	290.1	303.3	312	253.6	257.6	558.5	556.5	513.2	597.4	587.3	524.1	515
	Min 2024	214	232	233	69	70	460	457	423	509	502	436	434
	Max 2024	423	425	440	334	340	683	689	639	714	693	635	626
24-01	**27-28 Feb**	124	122	129	162	165	296	290	277	337	324	288	281
	12-13 March	111	109	110	142	137	256	255	233	284	278	236	229
	Mean 2024	144.9	156.9	162.9	146.5	145.9	301.3	299.5	277.3	327.9	322.2	285.4	281
	Min 2024	98	103	110	25	24	225	222	197	229	234	198	200
	Max 2024	335	347	364	180	174	520	514	485	643	542	498	499
01-02	**27-28 Feb**	92	92	89	108	107	198	198	192	221	218	190	183
	12-13 March	109	109	108	98	104	209	211	199	238	232	196	193
	Mean 2024	93.5	95.5	94.4	98.4	98.6	195	195.2	185.8	218.9	211.9	184.6	183.4
	Min 2024	80	79	75	44	42	169	175	163	197	188	166	165
	Max 2024	128	129	131	124	119	229	225	214	241	233	204	206
02-03	**27-28 Feb**	75	74	74	91	90	162	168	163	181	174	155	153
	12-13 March	66	64	67	101	100	162	165	159	176	176	158	156
	Mean 2024	71.4	72.5	73.6	96.7	95.7	168.9	170	162	178.6	176.9	156.6	153.6
	Min 2024	64	63	64	89	86	154	158	149	164	162	139	134
	Max 2024	83	84	84	104	104	189	190	178	193	198	170	167
03-04	**27-28 Feb**	68	72	74	119	118	197	198	184	200	200	164	160

Table 69: Traffic volumes closure phase A27

Traffic volumes A27 closure phase													
Section		**1**			**2**		**3**	**4**			**5**		
Time	**HMP**	**74.1**	**74.5**	**74.8**	**56.2**	**57.0**	**57.7**	**58.1**	**58.4**	**58.9**	**124.4**	**124.9**	**65.4**
	12-13 March	85	84	86	130	130	216	219	210	232	228	197	196
	Mean 2024	78.6	78.6	80.9	111.2	111.3	194.4	194.2	178.3	198.9	197.5	165.6	163
	Min 2024	68	70	74	85	83	161	161	146	174	172	137	136
	Max 2024	87	89	89	130	130	216	219	210	232	228	197	196

K.4 Mean average speed A27

Table 70: Mean average speed closure phase A27

Mean average speed A27 closure phase													
Section		**1**			**2**		**3**	**4**			**5**		
Time	**HMP**	**74.1**	**74.5**	**74.8**	**56.2**	**57.0**	**57.7**	**58.1**	**58.4**	**58.9**	**124.4**	**124.9**	**65.4**
22-23	**Mean 2022**	109.1	112.0	113.2	110.5	111.7	105.4	98.5	106.2	104.3	100.6	99.8	103.5
	Mean 2023	109.3	109.4	111.2	111.4	109.9	104.3	97.8	106.0	104.1	NaN	NaN	108.4
	Mean 2024	110.5	109.7	111.5	111.4	111.0	104.6	95.2	102.5	100.3	100.1	103.9	105.6
	Min 2024	107.8	107.5	108.2	105.3	107.5	97.1	63.2	75.9	66.3	73.9	78.5	76.5
	Max 2024	114.9	111.4	113.9	116.5	115.3	109.7	101.9	109.5	108.7	107.0	117.4	111.2
23-24	**Mean 2022**	106.4	109.9	111.2	109.8	111.0	104.9	99.7	107.8	105.7	104.5	106.8	108.9
	Mean 2023	109.6	110.3	111.1	112.3	112.6	106.6	99.2	109.0	107.4	NaN	NaN	110.2
	Mean 2024	108.5	109.8	110.7	110.1	109.6	104.4	96.3	105.1	103.4	102.4	105.5	107.6
	Min 2024	102.2	103.7	103.5	101.4	104.7	97.5	75.4	83.1	75.7	75.6	77.7	80.3
	Max 2024	113.5	113.9	113.0	114.5	112.9	107.1	102.6	109.5	109.3	108.1	124.5	112.6
24-01	**Mean 2022**	103.6	108.1	109.8	109.9	111.4	104.2	105.3	107.8	104.9	105.1	106.9	108.0
	Mean 2023	105.6	108.2	107.6	108.0	106.9	102.1	95.8	105.2	104.1	NaN	NaN	108.9
	Mean 2024	104.6	106.2	107.0	107.0	108.0	101.8	96.6	104.6	103.0	102.7	104.1	107.0
	Min 2024	97.1	98.2	98.7	100.7	100.8	96.2	91.3	85.3	78.7	79.4	81.1	84.2
	Max 2024	116.2	117.2	116.6	114.7	115.5	111.0	104.6	112.6	112.8	112.1	111.9	115.9
01-02	**Mean 2022**	95.1	99.8	100.9	103.1	97.8	97.7	92.9	100.9	102.2	101.1	103.9	103.3
	Mean 2023	92.7	94.8	102.7	107.1	108.2	100.8	95.1	104.4	102.9	NaN	NaN	106.5
	Mean 2024	96.8	96.4	100.1	106.5	107.2	99.0	93.4	100.9	98.8	99.9	103.3	104.3

Table 70: Mean average speed closure phase A27

Mean average speed A27 closure phase													
Section		**1**			**2**		**3**	**4**			**5**		
	Min 2024	92.5	91.9	95.7	102.8	97.6	96.3	88.8	84.2	79.0	77.6	79.7	82.4
	Max 2024	104.8	100.1	106.6	114.8	115.6	103.5	99.6	104.9	104.5	104.9	115.4	114.3
02-03	**Mean 2022**	94.0	101.4	103.6	101.7	106.0	96.8	94.6	102.2	96.2	100.6	101.7	101.7
	Mean 2023	94.9	94.8	99.0	107.6	105.6	99.2	89.3	101.3	101.1	NaN	NaN	103.1
	Mean 2024	95.5	101.5	102.5	101.3	100.0	97.9	88.4	98.0	98.1	97.8	98.9	100.2
	Min 2024	90.6	91.0	91.0	89.6	89.0	94.1	72.4	80.5	76.1	76.3	79.3	82.3
	Max 2024	104.8	110.0	111.4	115.6	107.7	102.7	97.8	104.9	104.1	106.1	110.1	110.6
03-04	**Mean 2022**	98.5	102.1	103.3	104.5	106.3	98.3	85.8	101.9	101.0	101.1	102.8	102.5
	Mean 2023	96.7	98.3	101.0	104.0	105.0	97.4	92.3	101.0	100.0	NaN	NaN	102.5
	Mean 2024	98.5	102.4	102.9	103.0	100.9	96.7	89.8	100.0	98.7	98.0	100.0	100.3
	Min 2024	91.3	97.3	98.3	94.2	90.2	90.2	71.5	96.8	93.6	88.3	94.7	97.1
	Max 2024	107.8	107.7	107.8	113.0	112.4	101.5	99.0	103.0	104.2	102.3	106.2	103.0

K.5 Average speed A27

Table 71: Average speed closure phase A27

Average speed A27 closure phase													
Section		**1**			**2**		**3**	**4**			**5**		
Time	**HMP**	**74.1**	**74.5**	**74.8**	**56.2**	**57.0**	**57.7**	**58.1**	**58.4**	**58.9**	**124.4**	**124.9**	**65.4**
22-23	**27-28 Feb**	111.6	111.4	113.1	110.4	108.5	105.5	100.5	107.4	105.8	105.9	109.4	111.0
	12-13 March	107.9	109.3	110.8	105.3	109.6	105.5	97.0	106.5	105.1	103.1	117.4	108.8
	Mean 2024	110.5	109.7	111.5	111.4	111.0	104.6	95.2	102.5	100.3	100.1	103.9	105.6
	Min 2024	107.8	107.5	108.2	105.3	107.5	97.1	63.2	75.9	66.3	73.9	78.5	76.5
	Max 2024	114.9	111.4	113.9	116.5	115.3	109.7	101.9	109.5	108.7	107.0	117.4	111.2
23-24	**27-28 Feb**	110.9	111.5	112.6	114.5	112.5	105.1	96.7	109.5	108.1	107.6	111.0	112.1
	12-13 March	105.3	107.5	110.2	108.5	109.7	104.3	98.3	106.8	106.2	105.6	124.5	110.3
	Mean 2024	108.5	109.8	110.7	110.1	109.6	104.4	96.3	105.1	103.4	102.4	105.5	107.6
	Min 2024	102.2	103.7	103.5	101.4	104.7	97.5	75.4	83.1	75.7	75.6	77.7	80.3
	Max 2024	113.5	113.9	113.0	114.5	112.9	107.1	102.6	109.5	109.3	108.1	124.5	112.6

Table 71: Average speed closure phase A27

Average speed A27 closure phase													
24-01	**27-28 Feb**	107.5	109.8	110.2	110.4	110.5	104.8	100.9	108.2	107.5	106.5	108.2	111.1
	12-13 March	100.0	104.5	109.4	108.3	109.2	100.9	91.3	105.1	104.0	102.7	111.9	106.1
	Mean 2024	104.6	106.2	107.0	107.0	108.0	101.8	96.6	104.6	103.0	102.7	104.1	107.0
	Min 2024	97.1	98.2	98.7	100.7	100.8	96.2	91.3	85.3	78.7	79.4	81.1	84.2
	Max 2024	116.2	117.2	116.6	114.7	115.5	111.0	104.6	112.6	112.8	112.1	111.9	115.9
01-02	**27-28 Feb**	92.7	94.7	96.9	104.5	103.9	98.3	96.2	100.2	102.7	101.3	105.3	107.3
	12-13 March	93.8	91.9	97.0	103.9	104.9	99.1	92.2	102.9	99.6	100.6	102.7	103.4
	Mean 2024	96.8	96.4	100.1	106.5	107.2	99.0	93.4	100.9	98.8	99.9	103.3	104.3
	Min 2024	92.5	91.9	95.7	102.8	97.6	96.3	88.8	84.2	79.0	77.6	79.7	82.4
	Max 2024	104.8	100.1	106.6	114.8	115.6	103.5	99.6	104.9	104.5	104.9	115.4	114.3
02-03	**27-28 Feb**	94.2	100.0	100.3	96.7	103.7	95.4	92.7	98.7	99.3	98.8	100.2	100.1
	12-13 March	90.6	107.1	91.0	112.3	96.2	97.7	97.8	104.9	99.5	98.4	98.8	102.7
	Mean 2024	95.5	101.5	102.5	101.3	100.0	97.9	88.4	98.0	98.1	97.8	98.9	100.2
	Min 2024	90.6	91.0	91.0	89.6	89.0	94.1	72.4	80.5	76.1	76.3	79.3	82.3
	Max 2024	104.8	110.0	111.4	115.6	107.7	102.7	97.8	104.9	104.1	106.1	110.1	110.6
03-04	**27-28 Feb**	96.8	107.7	107.8	97.4	100.1	95.9	94.0	99.4	99.0	102.3	102.8	102.2
	12-13 March	107.8	107.1	103.4	109.7	109.0	101.2	94.8	99.2	100.8	98.3	100.7	102.0
	Mean 2024	98.5	102.4	102.9	103.0	100.9	96.7	89.8	100.0	98.7	98.0	100.0	100.3
	Min 2024	91.3	97.3	98.3	94.2	90.2	90.2	71.5	96.8	93.6	88.3	94.7	97.1
	Max 2024	107.8	107.7	107.8	113.0	112.4	101.5	99.0	103.0	104.2	102.3	106.2	103.0