Hindrance reduction project Daelderweg

Bachelor thesis

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UNIVERSITY OF TWENTE.

Rijkswaterstaat
Ministry of Infrastructure and Water Management

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Preface

Before you lies the bachelor thesis “Hindrance reduction project Daelderweg.” This thesis has been written to fulfil the graduation requirements of the civil engineering program of the University of Twente. I worked on my bachelor thesis from 31th of October 2023 until the 26th of January 2024.

My interest in infrastructure projects and traffic management were the main reasons I decided to study civil engineering so this is what I wanted to do for my bachelor thesis. In the Netherlands Rijkswaterstaat is responsible for projects on the highways so I started to look for a project within Rijkswaterstaat. There was a possibility to do an assignment within the project Daelderweg and I had the possibility to adjust the assignment to my interests. I am grateful for the opportunity as it thought me to choose the scope which would be in my interests, possible with the accessible data and helpful for the project.

I want to thank my UT supervisor Eric van Berkum for providing me with useful feedback and asking critical question which helped me to look to my assignment from different angles. I also want to thank my supervisors at Rijkswaterstaat, Mariëlle van Dijk, Anke Westera and Tim van Peij for introducing me to the organisation, helping me to find the right people and providing me with information about the project. Finally, I want to thank my family and friends for their support during the writing of this thesis.

Martijn Kovacs

January 28, 2024

Abstract

With increasing traffic demand and ageing infrastructure extensive investments are needed to maintain Dutch infrastructure. In the south of the Netherlands the Ministry of Infrastructure and Water Management will invest in an overpass of the N298 that crosses the A76 highway since it is at the end of its lifespan and needs to be replaced. During the replacement of the overpass, the road will be closed to traffic and it will have an impact on the A76 highway. The goal of this thesis is to advise a set of measures that can reduce the hindrance caused by the road closures effectively.

In this thesis, a complete closure of the A76 highway near Nuth is considered, since this will most likely have the biggest impact on the area. During road closures it is required to have alternative routes via the main road network. In the Netherlands, there will be one via the A2/A79 and one via the N300. To determine the traffic hindrance in the area the average traffic intensities per hour are calculated for each hour during weekdays, weekends and summer holiday. Using the Nederlands Regionaal Model (NRM) (a Dutch traffic forecast model), the traffic allocation during road closures is determined. The current intensities (2022) and the increase in intensities during road closures (NRM 2030H) is used to calculate the intensity/capacity-ratio on different road segments on the alternative routes. This is also done for the intersections on the alternative routes since the capacity is lower and these are the bottlenecks of the alternative routes. To calculate the remaining capacity of these routes all the traffic that normally uses the A76 highway is redistributed over the network. Since the alternative routes will be used less if there are faster routes, the area is assessed for the possibility of rat running. Finally, the effects of the road closures on accessibility are assessed. The results of this assessment are used to determine the goals for the measures.

Rijkswaterstaat has a Minder Hinder approach which focuses on reducing hindrance during road works. It is divided into three main subjects Smart Planning, Smart Building and Smart Travel. The goal is to reduce hindrance for road users and other stakeholders, safety is a precondition, accessibility is the main focus and, measures that encourage smart mobility in the long term are favourable. These principles are used to determine the measures that can be used to reduce hindrance.

The results of the traffic hindrance analysis show sufficient road capacity, even during the road closures. The maximum hour intensities are 29% lower during the weekend in comparison to weekdays, which makes this the best period for the road closures. At the bottlenecks the capacity is not sufficient and traffic intensities should be decreased by 60%. The alternative routes have 10 minutes of additional travel time when there is no delay on these routes, this is within de conditions of the hindrance approach from Rijkswaterstaat. Finally, the accessibility in the region decreases, especially around Sittard-Geleen and Heerlen. The measures that will reduce the hindrance effectively are as follows:

- Road closures take place during weekend;
- Online and social media campaign;
- Employers approach by Zuid-Limburg Bereikbaar;
- Change traffic control scheme intersections;
- Kamp in Nuth only for destination traffic.

These measures will reduce the hindrance during road closures by minimizing delay and rat running.

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Definitions

FCD	Floating Car Data
IC-ratio	Intensity/capacity-ratio
LMS	National Model System
NRM	National Regional Model
SWOV	Institute for Road Safety Research

1. Introduction

The forecasts estimate that road usage will increase in the future (Ministerie van Infrastructuur en Waterstaat, 2023b). Many bridges and tunnels were built in the 50s and 60s and due to the increase in traffic some of the constructions need to be renewed. Road construction can result in major disruptions in local or regional traffic, to minimize the hindrance for the road users and inhabitants of the nearby area all the construction works must be coordinated, this ensures that there are not multiple construction works in the same area. Rijkswaterstaat plans all the maintenance and construction carefully and communicates in early stages to inform the road user of possible hindrance.

The Daelderweg, an overpass of the N298 that crosses the A76 highway needs to be replaced, since it is at the end of its lifespan. During the replacement of the viaduct, the Daelderweg will be closed to traffic. There may also be road closures on the A76 highway. These road closures will cause major traffic hindrance in the area if no measures are taken. Rijkswaterstaat wants to reduce the hindrance that is caused by the construction project.

The thesis starts with an overview of the project and an introduction to the stakeholders. Secondly, the problem will be analysed which is followed by an overview of the research objective and questions. Fourth, is the theoretical background with an explanation about traffic hindrance and hindrance reduction followed by comparable cases from the past. Fourth, the methodology that is used in the project is outlined. In the next part are the results that are found, which findings will be discussed and concluded in the next chapters. Finally, recommendations for further research will be given.

2. Project context

2.1. Project description

First, more information about the project will be given. The N298 is a provincial road that connects Valkenburg to Hoensbroek via Nuth. The overpass of the N298 between Hoensbroek and Nuth over highway A76 is at the end of its lifespan and needs to be replaced. Currently, there are two overpasses, one for each driving direction, these will be replaced with one overpass. Materials from the old overpass and overpass from elsewhere will be reused as much as possible (Ministerie van Infrastructuur en Waterstaat, 2022). During the replacement, the overpass will be closed. In figure 1 is an overview of the project area.

Figure 1: Overview project area (Google Maps, n.d.)

During reconstruction several scenarios exist that will all have a different impact on traffic in the area. Possible scenarios are as follows:

- Complete closure N298 overpass
- Speed limitations A76
- Lane closure A76
- Complete closure A76

2.2. Involved parties

The following stakeholders are involved in the project or will experience the effects of the road closures. The stakeholders will be described and their relation to the project will be given.

Rijkswaterstaat

Rijkswaterstaat is a government organisation from the Ministry of Infrastructure and Water Management. The goal of Rijkswaterstaat is to protect the Netherlands against floods, have a green environment, clean water and high accessibility where the inhabitants can travel fast and safely (Ministerie van Infrastructuur en Waterstaat, 2023c). To ensure this high accessibility in the future, Rijkswaterstaat is constantly maintaining and developing the road network. Rijkswaterstaat as road authority manages most highways (A-roads) and some motorways (N-roads). Many bridges, tunnels and overpasses were built between 1950 and 1970, the traffic intensities and the weight of the vehicles have only increased since, and this increased the risk of malfunctions. Therefore these constructions need to be renewed, Rijkswaterstaat monitors the state of these objects so the replacement or renovation process can start in time (Ministerie van Infrastructuur en Waterstaat, 2023e). These road works cause hindrance for the area, to ensure accessibility of the region the road works are coordinated and are communicated to the public in advance so that the road user can take into account the additional travel time.

Road users

The project area has three highways, the A2 which connects Amsterdam to the Belgium border, the A79 which connects Maastricht to Heerlen and the A76 which starts at the German border and ends at the Belgium border, it connects Heerlen to Geleen and has a connection to the A2 and A79. The A76 is the highway where the N298 overpass will be replaced. This will cause hindrance for all the ongoing traffic from Germany in the direction of Amsterdam in both directions and the regional traffic between Geleen and Heerlen. The measures will not only affect the road users of the N298 and A76 but also the road users on the surrounding and underlying road network. The users of the N298 and A76 need to use different routes to get to their destination, this can cause traffic congestion or longer travel times on these routes. For this thesis we consider the road user to be users who drive in motorized vehicles such as cars, buses and trucks.

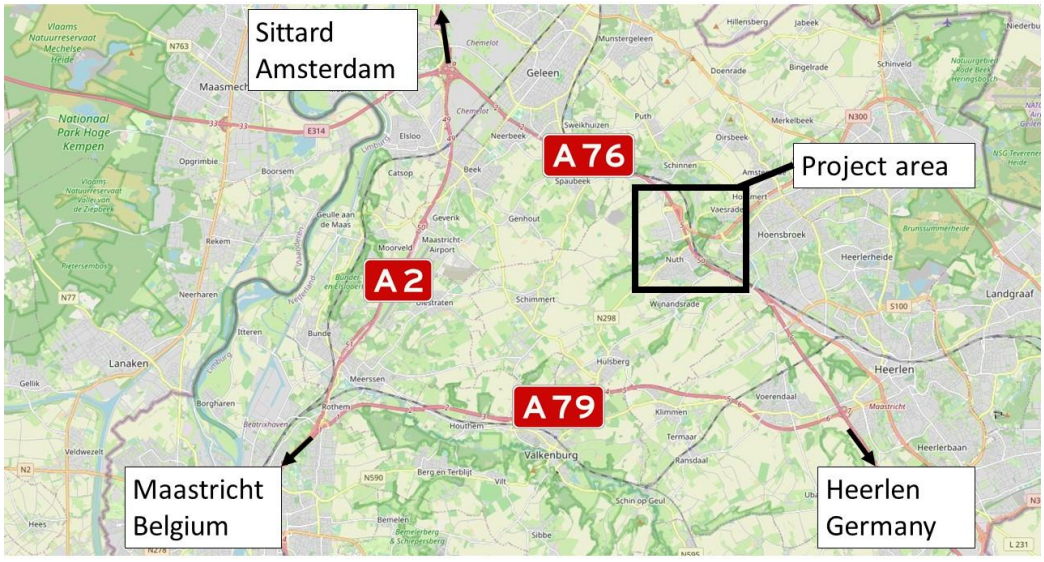

Figure 2: Overview area (OpenStreetMap contributors, 2023)

Province

The N298 is a provincial road which means that Limburg is the road authority that manages this road. The Daelderweg overpass is managed by Rijkswaterstaat, but the road on this overpass is managed by the province. The province needs to be informed of the upcoming project and road construction projects need to be coordinated so that there are no road closures in the area at the same time.

Cyclists and pedestrians

There are also other stakeholders which will be affected by the road closures. Other road users, for example, cyclists and pedestrians can also not use the N298 overpass and will have to use other routes to cross the A76. Another problem is that cyclists and pedestrians will experience higher traffic intensities on some roads. This could decrease the safety on some routes where the bicycle path is not separated, and crossing a road can take more time.

Public transport

The N298 overpass and A76 are used by two public transport lines. Bus line 56 uses the N298 overpass and line 631 uses the A76. The busses need to have alternative routes and some bus stops may be out of service during the road closures.

Businesses and inhabitants

Businesses and inhabitants in the area will also be affected by the road closures. The accessibility of the area can decrease due to longer travel times or having to use alternative routes and there could be higher traffic intensities on some roads. There is a business park adjacent to the N298, the N298 connects the business park to Nuth, when the overpass is closed the accessibility of the business park will decrease. There needs to be an alternative route so that inhabitants of Nuth can still access the business park.

Emergency services

Finally, for emergency services it will also become more difficult to reach their destination in the area. It needs to be communicated to the emergency service what alternative routes can be used, and other measures need to be taken to ensure the arrival times of emergency vehicles remain acceptable.

3. Problem analysis

In this chapter, the problem that is caused by the construction project will be analysed. In the past, a conceptual traffic analysis was carried out for the closure of the N298 overpass and A76. The analysis is executed using the Nationaal Regionaal Model (NRM), which is a regional traffic model of the Netherlands which can be used to make forecasts about transport usage. In this research, the travel demand from 2018 is used since it was assumed that as a result of COVID and hybrid working has evolved. The result is that 78.000 vehicles per day need to be redistributed onto the surrounding road network. The figure of the traffic allocation is in Figure 3. The red parts indicate an increase in traffic intensities and the green parts indicate a decrease in traffic intensities. There are only two routes which can be used as alternative routes, these are indicated with the blue arrows. The Minder Hinder Tool is developed by Rijkswaterstaat and calculates the effect on the additional travel time of individual vehicles on reroutes. This tool calculated that there will be traffic congestion during the entire day due to the lower capacity on bottlenecks. Only if the closures are in the summer period when there is less traffic there will be enough capacity on the reroutes (Verheijen, 2022). This conceptual traffic analysis made clear that without additional measures, there will be congestion on the road network which will result in longer travel times, a decrease in accessibility and a decrease in road safety due to the increase in rat running.

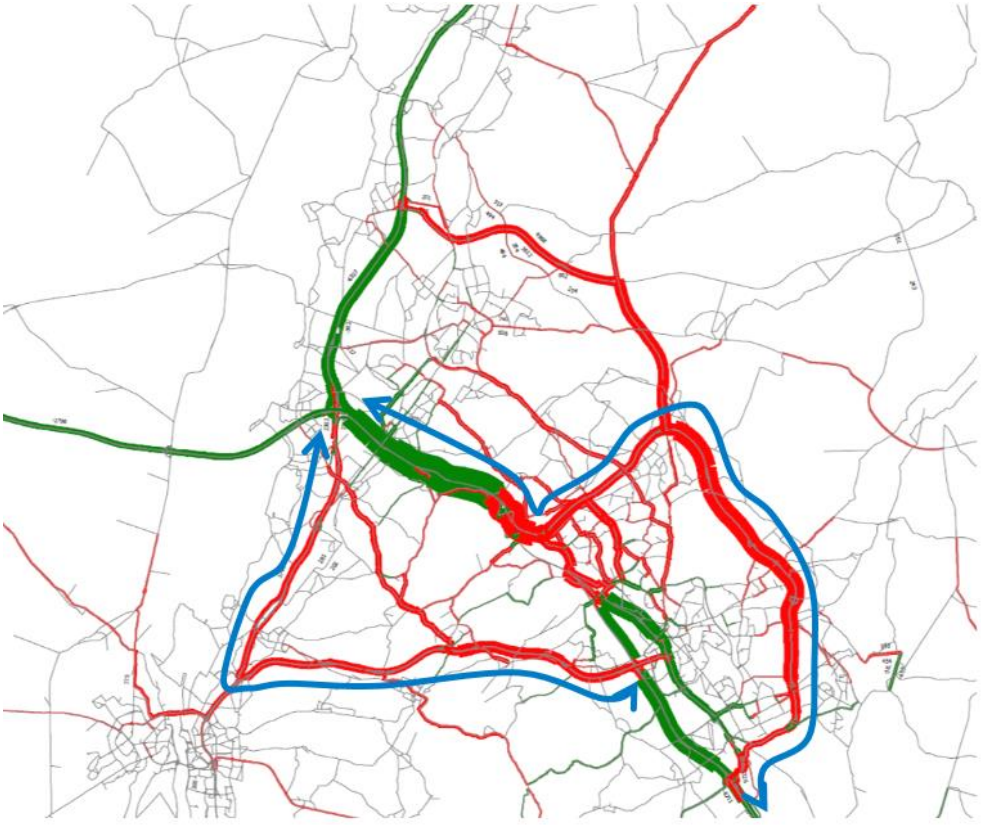

Figure 3: traffic allocation during closure N298 and A76 (Verheijen, 2022)

Rijkswaterstaat developed the Minder Hinder approach which is used to reduce hindrance. The main principles not only focus on hindrance reduction, but also state that safety is a necessary precondition. (Kernteam Hinderaanpak, 2023)

Problem statement

The Daelderweg overpass needs to be replaced as it is at the end of its lifespan, therefore the Daelderweg overpass and A76 highway will be closed for a period of time to make the construction possible. Rijkswaterstaat can only advise alternative routes on the main road system, but there are few alternatives, which are significantly longer in travel distance and time. The expected increase in traffic intensities on the other roads will lead to congestion and as a result cause traffic hindrance for the road users and the inhabitants and businesses in the area. This hindrance needs to be reduced without having negative side effects for road safety.

4. Research

4.1. Research scope

Scenario

During the replacement of the overpass, there are several possible scenarios which are mentioned in the Project description. The scenario that will be studied in this thesis is where the A76 highway under the overpass is also closed to traffic. This scenario is being studied as it will cause the most disruption since all traffic that would normally use the A76 will now have to be diverted to alternative routes. This will result in high levels of congestion on the surrounding road network if no measures are taken (Verheijen, 2022).

A76 highway

Due to the availability of data, the focus of this research will be on the traffic using the A76 highway. It will be taken into account that both the A76 highway and the Daelderweg are closed, but as there is no regional model available that can determine the effects of the Daelderweg closure in Nuth and the region, this thesis will focus on the effects of the traffic on the A76 highway that has to find alternative routes.

Traffic hindrance

The hindrance that is considered is delay, accessibility and safety. Due to the limited time scope of this thesis it is not possible to assess the hindrance for all aspects. What can be concluded from the previous research in the Problem analysis, is that the effects on the road system will be major and this will decrease the accessibility and cause delay for the road user. Safety is chosen since it is a necessary precondition for advising measures according to the Minder Hinder approach.

4.2. Research objective

To replace the overpass, the viaduct and the A76 highway will be closed to traffic, which will cause traffic hindrance. The objective of this research is to determine a set of measures that reduce the traffic hindrance caused by the closure of the N298 overpass and A76 effectively by analysing the effects on the road system during the road closures without measures. The measures should not have a negative impact on road safety

4.3. Research questions

The main research question follows from the research objective. This research question is then divided into sub-questions, the main research question is as follows:

- **Which set of measures reduces the traffic hindrance caused by the road closures on the N298 and A76 effectively?**
    - How can traffic hindrance be defined?
    - What are measures to reduce traffic hindrance?
    - How can traffic hindrance be determined?
    - What is the traffic hindrance caused by the road closures?
    - What are the bottlenecks on the road network?
    - How can these measures be assessed?

To answer this research question a desk research will be executed to define what hindrance is, and how this hindrance can be reduced. This information will be used to determine the hindrance that is caused by the measures by using traffic data and a traffic model. The results of this analysis will be used to assess the different measures and select the measures that are effective in reducing hindrance.

5. Theoretical background

5.1. Traffic hindrance

In this paragraph, the first sub-question will be answered: “How can traffic hindrance be defined?”. Traffic hindrance can be divided into two groups, objective traffic hindrance and subjective traffic hindrance. Objective traffic hindrance can be viewed from three perspectives, the road network, the road user and the external effects. Hindrance in the road network can be determined by traffic intensities and traffic speed. The effects on the road user can be determined by the travel times, travel distances and delays. The external effects are accessibility, air quality, noise pollution, safety and economic effects. Subjective traffic hindrance is the personal experience of road works, this can be caused by bad information provision, credibility, duration, time and location. Personal characteristics can also influence the perception of hindrance (Hermelink et al., n.d.). An overview of all traffic hindrance indicators is in Table 1. The scope of this thesis is limited to the delay, accessibility and safety. These indicators will be defined in the next parts.

Table 1: Traffic hindrance indicators

Category	Indicator	Unit
Hindrance on road network	Traffic intensities	vehicles/h
	Road capacity	vehicles/h
	Traffic speed	km/h
Hindrance for road user	Travel time	min
	Travel distance	km
	Delay	min
External effects hindrance	Accessibility	-
	Air quality	g/km
	Noise pollution	dB
	Safety	-
	Economic effects	€
Subjective hindrance	Hindrance perception road user	-

5.1.1. Delay

The first indicator that will be defined is delay. Traffic delay can be defined as “the additional travel time that is experienced by the road user due to conditions, incidents and events including, but not limited to road construction, maintenance activities, accidents, and avalanche closures. It is measured as the time difference between actual travel time and free-flow travel time” (Law Insider, n.d.). Traffic delay can be caused by traffic congestion or by longer travel times due to reroutes. Congestion happens when the traffic intensity exceeds the road capacity. Congestion can take place at regular intervals of time, for example during peak hours, or at irregular times which are unexpected, this can happen due to accidents or extreme weather conditions for example (Muneera & Karuppanagounder, 2018). In this project, delay is caused by the road closures that cause higher traffic volumes on other roads

Rijkswaterstaat uses the term congestion for three kinds of stagnant traffic: slow-moving traffic where traffic does not drive faster than 50 km/h over a distance of at least two kilometres, stationary traffic where traffic does not drive faster than 25 km/h over a distance of two kilometres, and finally slow-moving to stationary traffic, which is a combination of the first two situations (SWOV, 2022). Traffic congestion does not only have negative effects on travel times, it also affects the economy and social well-being of the road user negatively. Negative effects include an increase in fuel consumption, air pollution, vehicle wear and tear and noise pollution. Congestion also has a negative effect on road safety (Muneera & Karuppanagounder, 2018). Reducing congestion could also reduce the negative effects that are caused by the congestion, but this is dependent on how the congestion is reduced. What can be concluded from this is that if congestion is reduced it will not only reduce the delay for the road user, but also reduce other negative side effects.

5.1.2. Accessibility

The second indicator of traffic hindrance that will be defined is Accessibility. Accessibility can be defined as “the fact of being able to be reached or obtained easily” (Cambridge University Press, n.d.). At a local level this means that houses, businesses and facilities need to have a connection to the road system, even when there are road works there should be an option for road users to get to their destination. On a larger scale, the quality of being able to reach the destination can be seen as accessibility. A higher quality can mean shorter travel time or distance. Accessibility can be evaluated based on the time, money, discomfort and risk that is required to reach the destination. For quantifying accessibility activity-based and transportation models can be used (Litman, 2003). In this thesis the accessibility of Nuth will be assessed on a local scale and the regional accessibility will be assessed using a transportation model.

5.1.3. Safety

The last indicator of traffic hindrance that will be defined is safety. The safety of measures is a necessary precondition according to Rijkswaterstaat (Kernteam Hinderaanpak, 2023). Road safety takes into account that humans as road users are vulnerable, make mistakes and do not always follow regulations. This means that the road system needs to be designed in a way that reduces the chance of accidents, and if accidents happen the severity should be limited. The goal of the road system is to ensure accessibility and to provide for the mobility needs of the population. The SWOV Institute for Road Safety Research differentiates between eliminating, minimalizing and mitigating risk (SWOV, 2019). Eliminating risks is the best option if possible, it makes dangerous situations physically impossible so that people can not get in contact with these situations. Minimalizing the risk focuses on making the choice for dangerous situations or dangerous transport modes unattractive. This reduces the risk that people get in dangerous situations. Mitigating risks is to reduce the consequences when people get in dangerous situations.

The SWOV sustainable road safety strategy has five safety principles, three are for the design and two are organisational principles. For this thesis only the design principles are interesting. The design principles are functionality, (bio)mechanics and psychology. Functionality means that roads have only one traffic function for all transport modes (mono-functionality), a traffic flow function or an exchange function. The road system should also be built hierarchically. A road that has a flow function should mean that the traffic participation has no interaction with the environment while the purpose of a road with an exchange function is interaction with the environment. The hierarchy of the road network can be divided into three types of roads, the road types and functions are shown in Table 2 (SWOV, 2019). When analysing the difference in traffic intensities for the road closure scenario it is important to keep this road hierarchy in mind. It is not conducive to safety if the traffic intensities increase on access roads, or distributor roads with a lot of exchange segments.

Table 2: Road functions

Road type	**Function**
Through roads	Flow function
Distributor roads	Flow function on road sections Exchange function at intersections
Access roads	Exchange function

Furthermore, the design principle (bio)mechanics implies that traffic flows and modes of transport are compatible in speed, direction, mass, size and level of protection. For roads with a flow function, low-speed traffic must be separated from high-speed traffic. For a road with an exchange function, the speed must be lower, there also needs to be enough room for passing other road users. The last design principle, psychology implies that the design of the road system is aligned with the competencies of the road user. This means that the road system should be adjusted for the people who use it. (SWOV, 2019)

What can be concluded from this is that roads are designed for a specific function, during road works it is important that access roads are not going to be used as through roads. This is because access roads have many conflict areas and having an increased intensity of ongoing traffic on these roads can increase the chance of an accident happening. For some parts additional measures may be needed to ensure road safety, even when the traffic intensity increases, for example on distributor roads with many exchange segments.

5.2. Hindrance reduction

To answer the second research question: “What are measures to reduce traffic hindrance?”, the Minder Hinder approach by Rijkswaterstaat will be explained. The results of this approach will be analysed based on comparable cases from the past. Finally, a list of measures will be drawn up that can be used to reduce the hindrance for this project.

5.2.1. Minder Hinder approach

To determine the impact of the traffic hindrance Rijkswaterstaat uses different hindrance classes and hindrance categories. The hindrance classes are the impact on the individual road user and the hindrance categories define the total impact of the hindrance (Kernteam Hinderaanpak, 2023). An overview of all the hindrance categories is in *Table 3*, here can be seen that hindrance category A is the highest category and category E is the lowest. For each different category different measures are taken to reduce the impact. For most projects, there are different categories during the project phase because the hindrance class can change.

		< 1000	< 10.000	< 100.000	< 1.000.000	> 1.000.000
Class 0: no hindrance	-					
Class 1: minor hindrance	No traffic jam, delay < 5 minutes	E	E	D	C	B
Class 2: moderate hindrance	5 to 10 minutes delay caused by traffic jams or detour	D	D	C	C	B
Class 3: major hindrance	10 to 30 minutes delay caused by traffic jams or detour	C	C	B	A	A
Class 4: very high hindrance	30 to 60 minutes delay caused by traffic jams or detour	C	B	B	A	A

Table 3: Hindrance category matrix based on hindrance class and number of people impacted (Kernteam Hinderaanpak, 2023)

The hindrance category matrix can be used for the gross-hindrance, net-hindrance and reduced net-hindrance. The gross-hindrance is used to make a first estimation, in the planning phase the project plan can still be changed to a version that causes no or less hindrance. The (reduced) net-hindrance is later used to determine the final hindrance category. An important target value for the hindrance approach is that a road user should not be delayed for more than 60 minutes due to road works. The delay of a road user is defined by the additional travel time on the regular route at the time that the user normally travels. According to Rijkswaterstaat, congestion occurs when the intensity/capacity ratio (IC-ratio) is above 0,9 (Kernteam Hinderaanpak, 2023). When road measures are applied and the IC-ratio is below 0,9, no additional measures are needed. If the IC-ratio is above 0,9 additional measures may be needed. (Kernteam Hinderaanpak, 2023)

To reduce the hindrance during road works, Rijkswaterstaat has developed the Minder Hinder approach. This approach has four main principles, which are as follows (Kernteam Hinderaanpak, 2023):

1. the goal is to reduce the traffic hindrance caused by road construction works for all road users and other stakeholders.
2. Safety is a precondition.
3. The approach for hindrance reduction is primarily focused on maintaining accessibility as much as possible. Measures which contribute to road safety and sustainability or have long-term effects have priority. These measures are more likely to be implemented for hindrance reduction.
4. Citizens and businesses have a great responsibility for reducing and dealing with hindrance caused by construction works. Think of using a different route, different mode of transport, or travel during a different time. This is also the focus of mobility programs that stimulate smart choices in mobility.

Smart Planning

The Minder Hinder approach is divided into three main subjects, Smart Planning, Smart Building and Smart Travel. All these subjects follow the principles mentioned previously. Smart Planning is about the planning of the project. Not only the planning of the project itself is considered it is also coordinated with other road authorities, rail operators and cooperation partners. This coordination prevents that there are multiple construction works in the same area or on alternative routes so that the hindrance of one project increases the hindrance of another project. Rijkswaterstaat uses the following criteria to determine the time slots of projects (CROW, 2023a):

- No road works on alternative routes for other road works
- Not working simultaneously on parallel routes
- The road user should not be directed from one reroute to another reroute
- Not too many road works close to each other on one route

Smart Building

Smart Building relates to safe working practices and having contracts where safety measures and hindrance reduction are included. Smart Building provides a list of principles which can help to create contracts and project teams to find the best solution for the project. A project must have a traffic plan which has a hindrance analysis, alternative routes, remaining capacity on the road where the road works are located and remaining capacity of the alternative routes, public transport measures and a list of measures and expected results of these measures. Some of these measures are part of Smart Travel which is explained in the next paragraph. (CROW, 2023a)

Smart Travel

The third part is Smart Travel, for each hindrance category Rijkswaterstaat has a list of measures in four different domains. The domains are as follows, traffic management, communication, travel and route information and mobility management. For traffic management are no fundamental measures, for hindrance categories A and B it can be necessary to use mobility management measures. Important topics in mobility management are the stakeholders' approach, employer approach, encouraging public transport and bike usage and finally, P+R, hubs, and logistics. Measures for communication are focussed on advertising and using social media campaigns. There is also the possibility for additional web pages and press releases. Additional travel and route information is given via up-to-date maps, and mobility information on rijkswaterstaat.nl and the road works are also announced using social media. (Kernteam Hinderaanpak, 2023)

5.2.2. Transport planning model

Rijkswaterstaat uses two models to determine the traffic flows in the area, Landelijk Model Systeem (LMS) and Nederlands Regionaal Model (NRM). The LMS is a transport model of the Netherlands which can be used to make forecasts of the traffic intensities on the Dutch road system and make forecasts about the use of other transport modes. The NRM is the regional version of this model and makes it possible to make estimations on the level of road sections (Ministerie van Infrastructuur en Waterstaat, 2023d). The spatial models have divided the Netherlands into different zones with characteristics of the area, for example, the number of jobs, inhabitants, students and income. The model uses this data to estimate a transport mode, route and time of departure, this results in a model of all the traffic movements. By changing the characteristics of the zones or users, estimations can be made about future transport movements. The data in the model is verified with other models, for example, the provincial model, to ensure the reliability of the model (Ministerie van Infrastructuur en Waterstaat, 2017a).

The model will be used to create a reference scenario, this will be the traffic intensities on the road system with no additional measures, and a scenario with road closures on the N298 overpass and A76. The NRM will calculate the traffic assignment in each scenario and these traffic intensities will be used to determine possible delays and to determine where the intensities exceed the road capacity.

5.2.3. Comparable cases

- **Maintenance A79**

In 2021 maintenance was executed for the A79, and it was decided to carry out the work briefly and fierce, the project was executed in four phases. Each time a part of the A79 was closed for traffic in one direction, even though the strategy was brief and fierce, the hindrance was limited. Zuid-Limburg Bereikbaar is an organisation which wants to improve mobility in the region by working together with municipalities, the province, Rijkswaterstaat and other stakeholders in the region. The knowledge of the region, connections with organisations and great regional reach through various media channels increased the chance of success for mobility management measures. The following measures were deployed during the project (MuConsult, 2021):

- E-bike lending service
- Public transport try-out
- Informing businesses in the area
- Having an alternative route with a sufficient capacity
- Communication measures

The effects of these measures were successful 25%-30% of the road users that would use the closed road section in the reference period chose to work from home or use another mode of transport. This resulted in a limited increase in traffic intensities on alternative routes so there was no substantial delay on these routes. (MuConsult, 2021)

- **Maintenance tunnels A73**

In the summer of 2023, there was a major maintenance on the tunnels on the A73. Several technical installations needed to be replaced, to do this the tunnels were closed partially or in both directions. On a daily basis, 50.000 vehicles use the tunnels so it is chosen to execute the maintenance during the summer period when there is less traffic (Ministerie van Infrastructuur en Waterstaat, 2023a). During the road closures, there were several measures to reduce hindrance, a similar organisation as Zuid-Limburg Bereikbaar, Midden Limburg Bereikaar was involved and implemented mobility management measures and was used for communication with road users and businesses. The following measures were deployed during the project (MuConsult, 2023):

- E-bike lending service
- Public transport discount
- App Slimmer Reizen challenge
- Informing businesses in the area
- Having alternative routes
- Communication measures

The results of these measures are very promising, the measures have resulted in a traffic decrease of at least 50%-70% in comparison to the reference scenario. There was a limited increase on the alternative routes and the underlying road network, this indicates that a high percentage of the traffic that uses the A73 can use another mode of transport or has the possibility to not make the travel. The network of Midden Limburg Bereikbaar was used effectively to encourage businesses to inform their employees about the upcoming hindrance and look for other transport modes or travel less during the road closures. The hindrance was less than was expected beforehand, so apparently the communication to the road users was successful and road users decided to use routes outside of the region or travel not or differently. The public transport discount and e-bike lending service had relatively small effects but resulted in a small reduction in travel and the e-bike lending service even led to a structural effect where some users decided to keep the e-bike. (MuConsult, 2023).

5.2.4. Possible measures

Possible measures are in documents of CROW, which is the technology platform for transport, infrastructure and public space in the Netherlands. In the report traffic management for (road) construction projects is a list of measures that can be used to reduce hindrance. Rijkswaterstaat developed the Toolbox Smart Mobility which has important measures that can be used for mobility management. The measures are divided into the different goals of the measures.

- Increase road capacity
    - Change traffic control scheme

Traffic lights can create bottlenecks in the road network because the capacity of the intersection is lower than the road sections before and after the intersection. If due to road works the traffic intensities on a certain route increase the schedule of traffic lights could be changed so that this route has more green time and the capacity of the intersection increases. (CROW, 2023b)

    - Add temporary infrastructure

Add bottlenecks where the capacity is limited the capacity could also be increased by adding temporary infrastructure. This can be done at both intersections and road sections to increase capacity. It is a costly measure so it will only be implemented if other measures are not sufficient, and if the road works are for a long period of time. The costs can be reduced if there is an emergency lane available which could be transformed into an additional exit lane to increase the capacity of a highway exit and reduce the chance of traffic congestion on the highway. (CROW, 2023b)

- Decrease road traffic demand – Mobility management
    - Employers approach

Businesses are responsible for the commuter traffic, by informing businesses about the upcoming hindrance the employees can use different methods to reduce the total traffic demand. Employees could work at home or another location if possible or employees can carpool or use another mode of transport to decrease the traffic demand. Also, an e-bike loan service could be set up, where employees can temporarily use an e-bike to travel to work. (CROW, 2023b)

    - Park & ride

In case there is already a Park & ride available the costs of this measure are low, the shortage of parking spaces could limit the potential of this measure. The park & ride can be used by road users who can reach their destination via public transport and can travel to the park & ride location by car. The part they travel with public transport is to avoid the road closure which reduces the amount of traffic in the area. (CROW, 2023b)

    - Encourage the use of public transport

Encouraging the use of public transport can reduce the traffic intensities. This can be done by giving discounts in the area of the road works or by using a mobility card which can be distributed via employers so that employees can travel unlimited via public transport in the area. (CROW, 2023b)

    - Online and social media campaigns

Communication is the most important measure (E. Eussen, personal communication, December 19, 2023). During the maintenance on the A73, the traffic intensities were decreased by 50-70% which was the result of good communication about the road closures. A broad media campaign should be directed to many different target groups to reach as many road users as possible. Media interest can not only be achieved by announcing the road works, it can be more effective to inform about certain innovative aspects of the construction works or the mobility management. This attention can also be used to address the upcoming hindrance once more.

- Avoid congestion on the underlying road network
    - Set alternative routes

When a road is closed it is necessary to have alternative routes, these routes are indicated using road signs and Dynamic Route Information Panels (DRIP) if available. DRIPs could also inform the road user about the additional travel times and if there are more alternative routes available it could suggest the fastest route. The alternative routes must have sufficient capacity, which may need to be increased by changing the traffic control scheme to prevent or reduce congestion. (CROW, 2023b)

    - Approach for reducing rat running

Bottlenecks on the main road network can make a route via the secondary road network more attractive to a road user. If this route is not suitable for these increased traffic intensities measures should be taken to reduce rat running. Several measures can be taken to reduce rat running, the route could be made less attractive by lowering the speed limit and add speed lowering measures. It is also possible to make the road only available to exemption holders during peak hours, this is a costly measure which would only be possible by using traffic controllers during the road works (Ministerie van Infrastructuur en Waterstaat, n.d.-a). A more effective method of reducing rat running is solving the cause of the problem, bottlenecks on the main road network, which ensures that road users stay on the main road network.

- Reduce peak intensities
    - Use peak hour avoidance project

Some employees have the opportunity to avoid travelling during peak hours by car. This could be done by working at home, choosing a different mode of transport or travelling during off-peak hours. Using a rush hour avoidance approach this is actively stimulated by rewarding employees for each day they avoid travelling during peak hours. This could be monitored using license plate recognition or using an app. (CROW, 2023b)

- Reduce hindrance caused by construction work
    - Different planning for construction project

To reduce the hindrance that is caused by the construction project the planning could be changed. This can be done by executing the project during times when there is less traffic. For example in off-peak hours, during weekends or in vacation periods. Some projects can also be executed briefly but fierce, this causes a lot of hindrance but for a shorter amount of time which could have less hindrance in total. (CROW, 2023b)

6. Methodology

6.1. Traffic hindrance

In this paragraph the question: “How can traffic hindrance be determined?”, will be answered. It is required to advise alternative routes during road closures (Kernteam Hinderaanpak, 2023). These routes need to be via the main road network. There are two possibilities in this area, one area via the A2/A79 and one via the N300. The alternative routes and the reference route are in Appendix A : traffic analysis. The traffic hindrance will be determined for the road closures where these alternative routes will be advised.

6.1.1. Delay

To determine the delay that road users will experience the travel times on the reference route and alternative routes will be compared. The travel time in a free-flow scenario is determined by using Google Maps and selecting the shortest possible travel time on the route. Only the travel time during the day is considered because the speed limits on the A76 and A2 are higher between 7 p.m. and 6 a.m. (130 km/h vs 100 km/h). The average travel time during peak hours is calculated by using Floating Car Data (FCD). FCD is combined data from GPS-positions of several navigation systems, for example, phones and navigation systems in cars. This data can be combined to calculate the average speed (NDW, n.d.). For the alternative routes data from 2023 is available, the peak hours are considered to be between 7- 9 a.m. and 4 – 6 p.m. during weekdays. Holidays are excluded from the data to calculate reliable travel time during peak hours. The average delay will be used to determine if the additional travel time that is caused by the road closures is acceptable.

Remaining capacity road network

The average delay that road users will experience is in a reference scenario where the congestion on the road system is limited. Congestion will occur if the IC-ratio is above 0,9. The traffic intensities need to be compared to the capacity of the road network to determine the IC-ratio during the reference scenario and the road closures.

The traffic intensities on the road are determined by using the actual traffic intensities in 2022. The traffic intensities on the road system are determined for a couple of points on the road system. These points are on the original route or one of the alternative routes and combined they will give an indication of the traffic intensities on these routes. An overview of these reference points is shown in Figure 4. For the capacity of a road the Passenger Car Equivalent (PCE) is used. This number is used to determine how much space a vehicle takes up compared to a passenger car. Rijkswaterstaat uses a PCE of 1,75 for trucks. The capacity of the road network is expressed in PCE, the traffic intensities are expressed in vehicles per hour. To calculate the Intensity/Capacity-ratio (I/C-ratio) of the road the intensity and capacity both need to be expressed in PCE. The percentage of trucks on each road segment is included in the traffic intensity data. It is assumed that the relative percentage of trucks remains the same during road closures. The capacity of all the roads can be found in the mobilityscan of Rijkswaterstaat. The mobilityscan is an online tool of Rijkswaterstaat which can be used to make analyses concerning spatial planning and traffic engineering. It can be used to determine the effects on mobility and sustainability and it uses data from different traffic models, for example, the NRM, and traffic data. It is used to calculate the effects of hindrance reduction measures, and it can be used to determine the accessibility of jobs and inhabitants in the area (Ministerie van Infrastructuur en Waterstaat, n.d.-b). The traffic intensities and capacities can be combined to determine the I/C-ratio of each reference point. This gives an overview of the traffic intensities in the area. In order to compare the I/C-ratio during different periods, weekdays, weekends and summer holidays are included in this study.

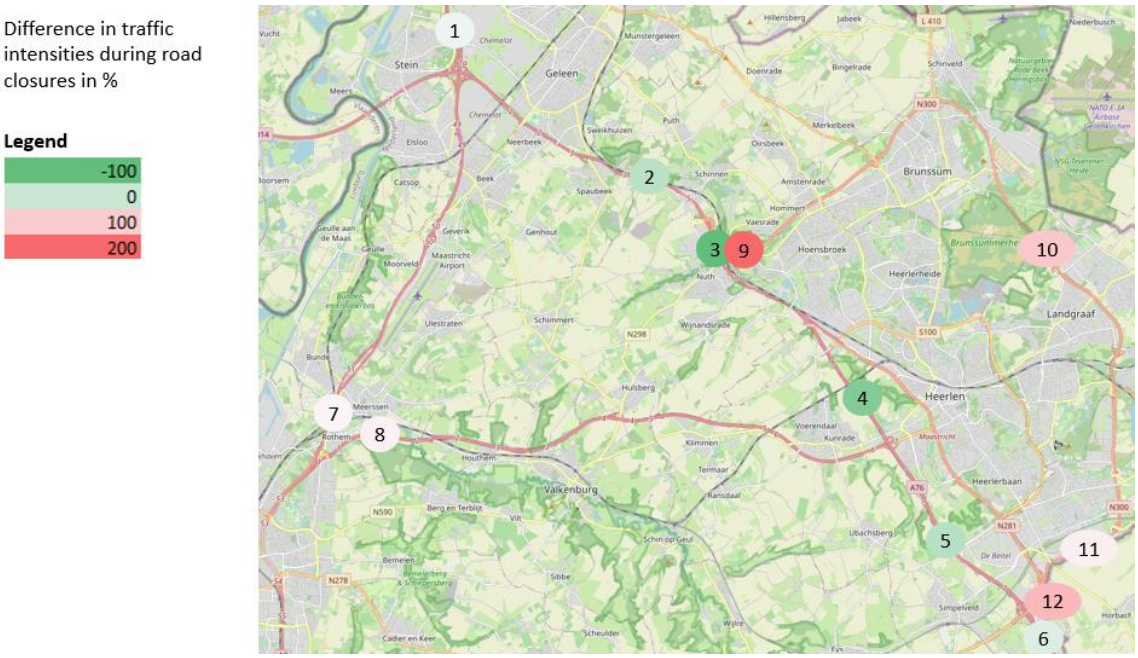

Figure 4: Difference in traffic intensity during road closures (OpenStreetMap contributors, 2023)

Remaining capacity bottlenecks

Road capacity is higher on the through road network than on the exits and intersections. These intersections will be considered as the bottlenecks. To determine how much capacity there is left on the road system the capacity and intensity of these bottlenecks are calculated. An overview of the bottlenecks is in Figure 6. Of each bottleneck is a more detailed overview in Appendix A : traffic analysis.

The remaining capacity of the bottlenecks is calculated through the NRM (2030H scenario) and traffic intensities (Mobility scan).The capacity and percentage of trucks is gathered from the mobilityscan. By using the percentage of trucks the intensity can be calculated in PCE/h. The remaining capacity is in PCE per hour, and is calculated for the evening peak hours since these have the highest traffic intensities in this area. To get more accurate results of the remaining capacity on the bottlenecks a different method will be used. The average intensities during peak hours are already calculated for the reference points. It would be preferable if the capacity of the alternative routes is sufficient so that the ongoing traffic on the A76 can use the alternative routes with minimal delay. All the traffic that normally uses the A76 will be diverted over the alternative routes, this will give a new remaining capacity which is more reliable.

6.1.2. Safety

To ensure that the measures have no negative side-effects on road safety the roads should be used for their intended use. This means that rat running should be prevented, possibilities of rat running can be found in the NRM. In the traffic assignment of the NRM is visible that there are also other routes which have increased traffic intensities. These routes need to be identified because they can cause additional hindrance for the area. The routes that are selected have a significant increase in traffic during the road closures and are shortcuts for the alternative routes.

6.1.3. Accessibility

The accessibility of the area can be calculated using the mobilityscan. The accessibility is divided in two parts, the local accessibility and regional accessibility. The local accessibility will focus on the accessibility of the business park Nuth and the accessibility of Nuth. The regional accessibility is calculated with the mobilityscan and will give insights in how the accessibility decreases with the road closures.

The mobilityscan can calculate the potential accessibility of different areas, the mobilityscan uses the development opportunities for this. It determines from which areas jobs or inhabitants can be reached easily. This accessibility value (*bw*) is calculated using the following Equation 1 (Ministerie van Infrastructuur en Waterstaat, 2017b).

$$bw_{od}^{m} = \alpha_{bw}^{m}[\frac{t_{od}^{m}}{100}]^{\beta_{bw}^{m}}$$

Equation 1

Where:
α, β = accessibility parameters
t = travel time in minutes
This accessibility value is calculated for each origin-destination (*od*), where for cars α = 80 and β = 3,5. The accessibility value are summed across all origins and destinations. Afterwards the accessibility values are sorted from large to small and divided in 5 equal parts, and each zone gets a corresponding colour to how accessible they are.

6.2. Assessment measures

To determine which set of measures are the most effective the effects of the measures need to be predicted. It is also important that possible side effects of the measures, for example, safety, are considered so that measures do not have negative side effects that outweigh the benefits. But first, the goal of the measures needs to be defined.

6.2.1. Goal measures

The goal of the measures is to reduce the traffic hindrance caused by road closures without having a negative effect on road safety. To reduce the traffic hindrance the additional travel time needs to be limited and to ensure road safety it is important that the traffic uses routes that follow roads which have a flow function. For this two alternative routes are suggested which are on the main road network and have an additional travel time of approximately ten minutes when there is no additional delay. This additional travel time is shorter than via most shortcuts, to prevent rat running the additional travel times on the alternative routes should be limited. This can be done by increasing the capacity of the alternative routes or by decreasing the traffic demand on the alternative routes. As is calculated in 7.1.1, the traffic demand needs to be decreased by 20-60% or the capacity of the bottlenecks should be increased.

6.2.2. Possibility of measures

To determine which measures together can be used in the advice, the possibility of the measures in this project will be discussed. The conclusion of the maintenance project of the A73 in the summer of 2023 and the expert interview with Eric Eussen is that the combination of some measures together is what makes the measures effective because they enforce each other. This is why some measures are discussed in combination. It is also that the effects of the online and social media campaign and employers approach can not be measured individually. The decrease in traffic intensities in the area is the indicator that is measured, it can not be tracked if this is due to the media campaign or the employers approach.

- Online and social media campaigns

Communication is the most important measure (E. Eussen, personal communication, December 19, 2023). This can be seen in the result of the measures during the maintenance of the A73 highway. An online and social media campaign is not only about informing road users about the upcoming road closures or hindrance, but also about offering alternatives. These alternatives are other measures, for example, alternative routes or public transport. There are also other ways to increase awareness of the upcoming hindrance, for example with news articles about interesting details about the project. In this case, it could be about the circularity of the new overpass, a news article about this will also mention the upcoming road closures during the construction of the overpass.

- Employers approach

The employers approach uses direct communication with businesses via a local organisation to discuss the possible hindrance and look for alternatives that will reduce the hindrance for the business and reduce the traffic demand on the road system. This is enforced by offering alternatives as encouraging public transport use, or the e-bike loan service. The effects of the e-bike loan service and public transport are limited, but in combination with a broad online campaign, it can reduce traffic demand by 50-70% (MuConsult, 2023). Zuid Limburg Bereikbaar is an organisation that is active in the region and is in contact with businesses in the region. The organisation was also active during the A79 maintenance in 2021, so it would be helpful if this organisation would play a role in mobility management again.

- Set alternative routes + approach for reducing rat running

This is already discussed in previous parts and having alternative routes is required during road maintenance projects. DRIPs are already next to roads on most routes, but additional ones could be placed. These DRIPs could inform the road users about the possible alternative routes and divide the traffic over the routes so that the delay on both routes is limited. The alternative routes are also important for avoiding rat running. Rat running is increased if there are delays on the main routes and road users start to look for alternatives. Another approach to reduce rat running is making routes via the underlying road network less important, this would be necessary for the shortcut via Kamp.

- Use rush hour avoidance project

During the maintenance of the A73 highway, an app was used to support smart travelling. This could mean travelling using another mode of transport, not making the travel or outside of peak hours. The effect of this app was very limited, this was the same result for the A79 project where there was no shift in travel to the off-peak hours. Since the effect of rush hour avoidance projects is very limited it could be included in the online campaign, but using a different app to support this is not an effective measure.

- Different planning construction project

The planning of a construction project could be changed by changing the time and the duration in which the project is executed. For this project, it would be best if it is executed in the weekend since the maximum traffic intensities per hour are lowest in this time period. The planning for the construction project could also be changed by changing how the construction is executed. There could be possibilities for executing the project while keeping one lane available in each direction on the highway. Since this is out of the scope of the thesis this option will not be considered.

- Change the traffic control scheme

By changing the traffic control scheme the direction of the traffic on the alternative route can be given priority. This increases the capacity of the bottleneck. 4 of the 5 bottlenecks have traffic lights, so changing the traffic control scheme to increase the capacity on these routes could have a big impact on the capacity of the routes.

- Add temporary infrastructure

This is a very expensive method and it is improbable that it will be implemented for short-term road closures. In this case, there is no additional space available at the intersections which could be used as an additional lane, this means that new infrastructure needs to be built and due to the landscape in the region (large height differences) this would need big investments to make the area suitable. Therefore this measure will be a last resort and only be implemented if all other measures are not sufficient.

- Encourage the use of public transport + Park & ride

The use of public transport can only be encouraged if it is a good alternative in the area. The encouragement of public transport is more effective if it can also be used by road users who do not have a public transport connection to the train station. This can be solved by having parking spaces available so that these users can drive to the train station. There are two train stations near the road closures. Station Nuth can be accessed by road users that have the origin in the Southern part of the road closures. Station Schinnen can be accessed by road users that have the origin in the Northern part of the road closures. Road users could also use other train stations in the region, for example, Heerlen or Sittard. These stations have a direct and fast train connection to each other and other cities in the region. In the select link analysis of the A76 near Nuth in Figure 5, on the left side is the analysis in the direction Heerlen to Geleen, and on the right side from Geleen to Heerlen. The green circles are origins and the red circles are destinations. The size of the circles is related to the number of trips that are made from that location. In this analysis can be seen that a lot of origins and destinations are near Heerlen, Sittard and Geleen. These locations all have train stations which makes public transport a good alternative. This means that promoting public transport as an alternative travel mode is a good idea for the media campaign, but using mobility cards for employees in previous projects had little result it is not necessary to do both.

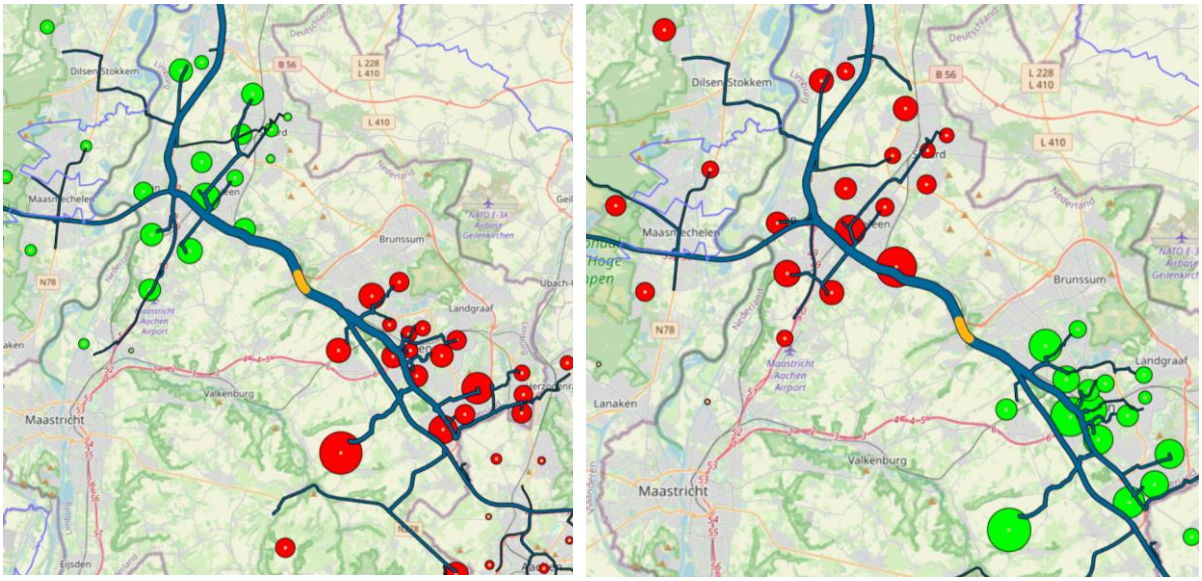

Figure 5: Selected link analysis (Personal adaptation Mobiliteitsscan, 2024)

6.2.3. Criteria measures

The measures will be assessed for different criteria, this assessment is later used to determine which measures will be put into an advice. The criteria will be scored using the score levels in Table 4. The result of the assessment is in Assessment measures.

Table 4: Score levels

+ +	High positive impact
+	Positive impact
+ -	Neutral
-	Negative impact
- -	High negative impact

Safety

The most important criterion is safety. As is concluded in 5.1.3, roads are designed for a specific function. To ensure road safety the road should also be used that way. This means that roads with an exchange function should not be used by ongoing traffic, which is mainly caused by rat running. This means that measures which decrease rat running have a positive effect on road safety. Measures which decrease the traffic demand also have a positive effect on road safety, because fewer cars on the road system also means a lower probability of an accident happening.

Decrease traffic demand

One of the goals of the measures is to reduce the traffic demand. The effects of the measures will be based on the effects of these measures in previous maintenance projects.

Increase road capacity

The other goal of the measures is to increase the road capacity. This increase will only be on certain road segments or bottlenecks on the alternative routes, an increase in capacity will reduce the maximum I/C-ratio and reduce the chance of traffic congestion.

Reduce traffic demand during peak hours

The biggest problems occur during peak hours, this is when the I/C-ratios are highest. When lowering the traffic intensities during peak hours the I/C-ratios decrease and the chance of traffic congestion is reduced.

7. Analysis and results

7.1. Traffic hindrance

7.1.1. Delay

The results of the average travel times are in Table 5, here can be seen that the average delay that road users will experience is around 10 minutes. This is acceptable according to the Minder Hinder approach (Kernteam Hinderaanpak, 2023). What can be concluded from this is that the delay is acceptable if there is no increase in congestion on the alternative routes.

Table 5: Information alternative routes

Routes	Direction	Route length (km)	Travel time free flow (min)	Average travel time peak hours (min)
Reference route (A76)	(N-S)	24,5	14	16,5
	(S-N)	24,2	14	15,2
Alternative route 1 (A79/A2)	(N-S)	36,4	22	24,7
	(S-N)	36,9	22	23,5
Alternative route 2 (N300)	(N-S)	37,2	24	26,9
	(S-N)	36,0	22	23,9

Remaining capacity road network

An overview of the maximum I/C-ratio for each reference point in each scenario is shown in Table 6. Here can be seen that the maximum I/C-ratios are lower during the weekends in comparison to the summer holiday. On almost all road segments there is also still sufficient capacity, even during the road closures.

Table 6: Overview max I/C-ratio reference points

Reference point	Description	Direction	max I/C-ratio weekdays	max I/C-ratio weekend	max I/C-ratio summer holiday	max I/C-ratio weekdays during road closures	max I/C-ratio weekend during road closures	max I/C-ratio summer holiday during road closures
1	A2 North	N-S	0,70	0,48	0,53	0,63	0,44	0,48
		S-N	0,60	0,41	0,51	0,53	0,36	0,45
2	A76 North	N-S	0,90	0,62	0,68	0,49	0,34	0,37
		S-N	0,86	0,61	0,72	0,49	0,35	0,41
3	A76 Nuth	N-S	0,64	0,48	0,52	0,00	0,00	0,00
		S-N	0,67	0,46	0,59	0,00	0,00	0,00
4	A76 Heerlen	N-S	0,26	0,25	0,29	0,06	0,05	0,06
		S-N	0,23	0,22	0,30	0,09	0,09	0,12
5	A76 Simpelveld	N-S	0,34	0,29	0,34	0,19	0,16	0,18
		S-N	0,30	0,30	0,39	0,19	0,19	0,25
6	A76 South	N-S	0,33	0,32	0,35	0,27	0,25	0,28
		S-N	0,39	0,36	0,42	0,31	0,29	0,33
7	A2 South	N-S	0,73	0,51	0,57	0,80	0,56	0,62
		S-N	0,73	0,52	0,63	0,79	0,57	0,68
8	A79	E-W	0,54	0,31	0,35	0,61	0,35	0,40
		W-E	0,49	0,27	0,35	0,55	0,30	0,39
9	N300 Nuth	E-W	0,41	0,23	0,22	1,18	0,67	0,63
		W-E	0,41	0,21	0,24	1,19	0,61	0,69
10	N300 Landgraaf	N-S	0,33	0,21	0,21	0,55	0,34	0,35
		S-N	0,35	0,21	0,25	0,60	0,35	0,42
11	N300	E-W	0,37	0,22	0,22	0,43	0,25	0,26
		W-E	0,38	0,20	0,26	0,44	0,23	0,31
12	N281	E-W	0,34	0,28	0,30	0,63	0,53	0,55
		W-E	0,32	0,29	0,27	0,47	0,42	0,40

Remaining capacity bottlenecks

Since the capacity on the ongoing road segments is higher than on the intersections, it is important to calculate if there is sufficient capacity on the bottlenecks. To determine how much capacity there is left on the road system the capacity and intensity of these bottlenecks are calculated. In Figure 4 the difference in traffic intensities during road closures can be seen, There will be a decrease in traffic on the A76, but an increase on the A79, A2 and N300 on which is still sufficient capacity. An overview of the bottlenecks is in Figure 6. Of each bottleneck is a more detailed overview in Appendix A : traffic analysis.

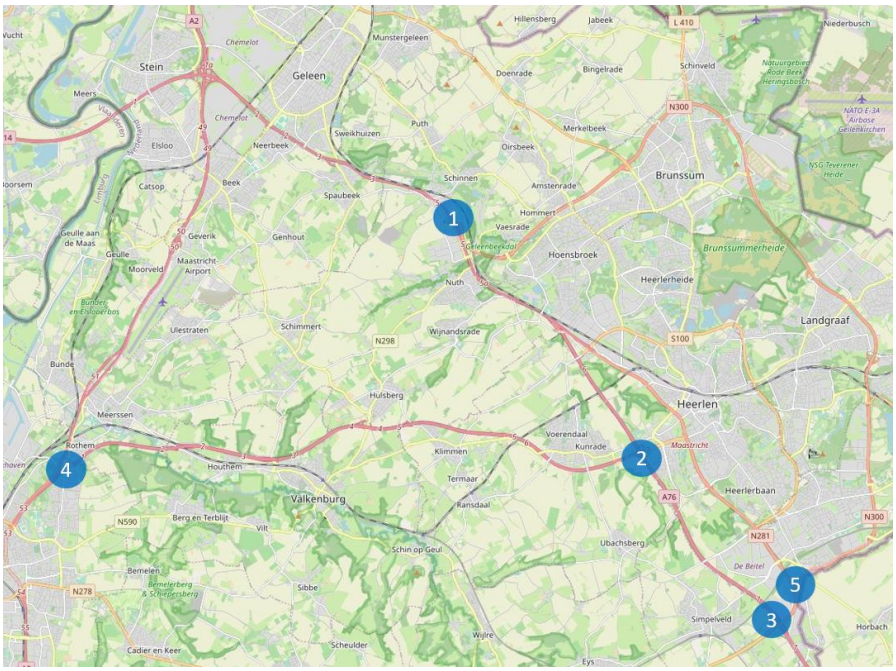

Figure 6: Bottlenecks area(OpenStreetMap contributors, 2023)

Table 7: details bottlenecks

Bottleneck	Direction	Intensity vechicles NRM 2030H (veh/h)	Percentage trucks	Capacity (PCE/h)	Intensity (PCE/h)	Increase intensity NRM (PCE/h)	New intensity (PCE/h)	Remaining capacity (PCE/h)
1	N300-A76	988	16,8	2008	1112	206	3404	-1396
	A76-N300	836	13,2	2008	919	137	2178	-170
2	A76-A79	513	8,6	2175	546	33	726	1449
	A79-A76	603	12,2	2175	658	36	895	1280
3	A76-N281	556	13,2	2175	611	29	788	1387
	N281-A76	364	9,4	1088	390	63	635	453
4	A2-A79	420	14,5	480	466	47	685	-205
	A79-A2	289	22,4	1305	337	50	506	799
5	N298-N300	265	15,5	1575	296	131	683	892
	N300-N298	219	15,6	1575	245	143	595	980

The remaining capacity of the bottlenecks is calculated through the NRM (2030H scenario) and traffic intensities (Mobility scan).The capacity and percentage of trucks is gathered from the mobilityscan. By using the percentage of trucks the intensity can be calculated in PCE/h. The results of these calculations are in Table 7. The remaining capacity is in PCE per hour, and is calculated for the evening peak hours since these have the highest traffic intensities in this area. It is clear that bottleneck 1 and 4 have an insufficient capacity during the road closures and delays will occur. Bottleneck 3 and 5 have a limited remaining capacity, the increase in traffic intensity is calculated by the NRM, in the redistribution of the NRM road users also use other routes to get to their destination instead of the advised routes. Road users will only use the advised route if the travel time is within acceptable limits, preferably it should be shorter than via shortcut routes. The reliability of the travel times can be increased by having sufficient capacity on the road network. This means that the remaining calculated capacity can be too high, therefore the remaining capacity will also be calculated using another method.

To get more accurate results of the remaining capacity on the bottlenecks a different method will be used. The average intensities during peak hours are already calculated for the reference points. It would be preferable if the capacity of the alternative routes is sufficient so that the ongoing traffic on the A76 can use the alternative routes with minimal delay. The maximum average traffic intensities during peak hours is 2612 vehicles per hour in N-S and 2761 S-N. The average increase on the route via the A2/A79 was 41,5% in both directions, and the average increase on the route via the N300 was 114,3% and 122% from N-S and S-N respectively. This ratio will be used to divide the traffic over the routes, in Table 8 the increase in intensity for each route is calculated. When this increase in intensity is added for each bottleneck the remaining capacity can be calculated, this is shown in Table 9. For a smooth traffic flow the traffic demand should be decreased by 40-60%.

Table 8: Increase intensity per alternative route

		Average increase intensity in %	Ratio	Intensity increase on route veh/h
Route A2/A79	N-S	41,5	0,27	695,6
	S-N	41,5	0,25	700,8
Route N300	N-S	114,3	0,73	1916,4
	S-N	122	0,75	2060,2

Table 9: Remaining capacity bottlenecks

Bottleneck	Direction	Intensity NRM 2030H (PCE/h)	Increase intensity route (PCE/h)	New intensity (PCE/h)	Remaining capacity (PCE/h)
1	N300-A76	1112	2197,7	3310	-1302
	A76-N300	919	2051,5	2970	-962
2	A76-A79	546	747,6	1294	881
	A79-A76	658	744,6	1403	772
3	A76-N281	611	2197,7	2809	-634
	N281-A76	390	2051,5	2441	-1353
4	A2-A79	466	744,6	1210	-730
	A79-A2	337	747,6	1085	220
5	N298-N300	296	2197,7	2493	-918
	N300-N298	245	2051,5	2296	-721

7.1.2. Safety

An overview of the possible routes for rat running are in Figure 7, the expected increase in intensity are in Table 10. The route that will be used most is route 3, which is a shortcut that can be used to bypass the junction of the A76. The travel time of this route is 22 minutes during free flow and 30 minutes during peak hours, this is longer than the alternative routes. The distance of the route is 27,1 km, so the distance is shorter than one of the alternative routes. The route may be faster for local road users, but the route is through residential areas so it would cause a lot of hindrance for the inhabitants and have a negative impact on the road safety. The capacity is also very limited which will result in a longer travel time if the route is frequently used. Route 1 is another shortcut, this route is used by road users that take the alternative route via the A79 and A2, but avoid the intersection Kruisdonk (A79/A2). The travel time during free flow and peak hours is 24 minutes and 30 minutes respectively. The route length is 27,9 km which means that this route also has a longer travel time but a shorter travel distance. This route is through village centres so it will have a negative effect on the road safety and cause hindrance for the inhabitants. Route 4 has an increased intensity not because it is used as a shortcut, but because road users in the area that normally enter the A76 via the N281 now need to enter the A76 via the N300. Route 2 is used by inhabitants in and nearby Nuth, in the NRM this is the shortest route to get from the centre of Nuth to Geleen. In the real situation there is another road available which could be used to get to the A76 and travel to Geleen, so in the real situation this road will probably have less traffic increase. Route 5 will probably be used by traffic that is coming from the area around Sittard which would normally use the highway, but now travel via Germany and the N300 to get to their destination. Finally, there is route 6 which is not in the NRM model, because it uses a road that is not in the model, this is because it is a small with no separated bike path trough a residential area. The travel time during free flow would be 18 minutes and it has a distance of 25,9 km. This makes this route shorter and faster than the alternative routes, the road needs to be available for the inhabitants of Nuth to access the business park but should not be used for ongoing traffic, because this will cause dangerous situations and traffic congestions in the residential areas in Nuth.

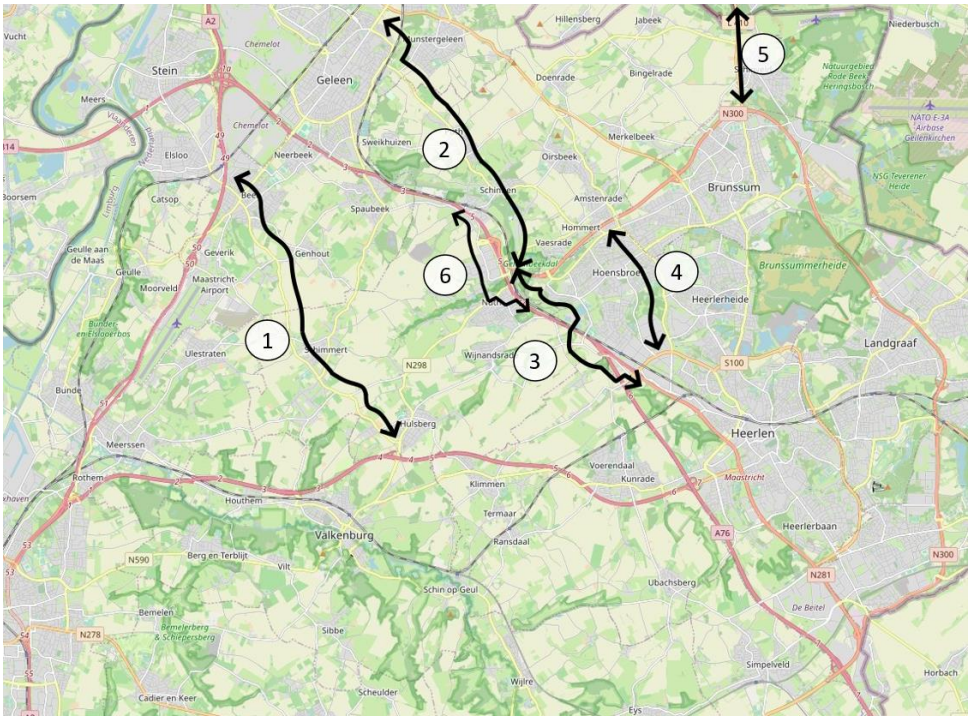

Figure 7: Other routes(OpenStreetMap contributors, 2023)

Table 10: Increase intensities shortcuts

Route	Expected increase in intensity in %
1	50-90
2	80-140
3	50-3370
4	60-100
5	60-70
6	unknown

7.1.3. Accessibility

Local accessibility

As can be seen in Figure 8 the business park can now only be accessed via a small road. This could be an option for the local inhabitants but it should only be used for inhabitants who have the business park as destination and not for ongoing traffic which wants to use this as a shortcut. The road has no separated bike path so if the traffic intensities increase it will reduce the road safety.

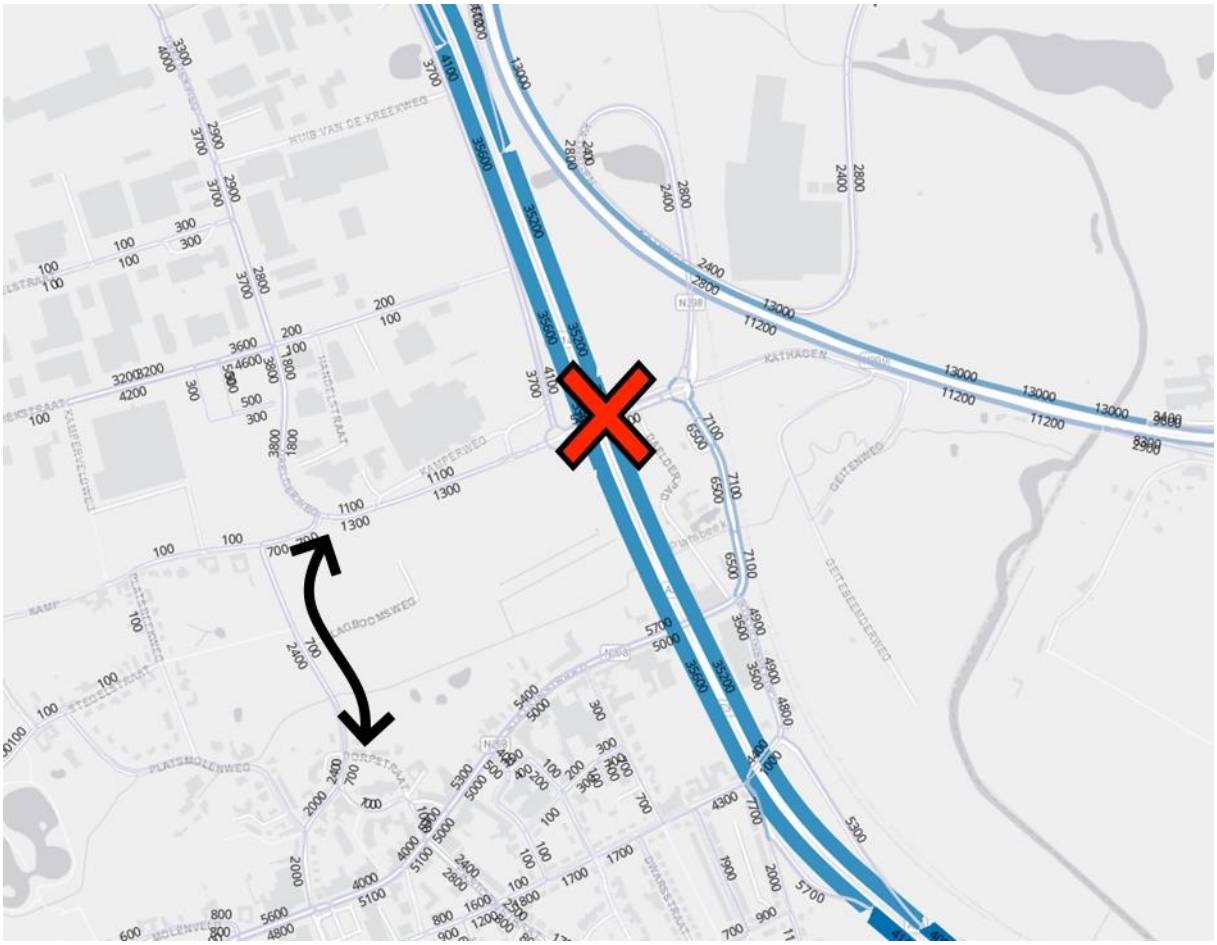

Figure 8: Overview Nuth

Regional accessibility

An overview of the change in accessibility in the region is in Figure 9. Here can be seen that the accessibility nearby Heerlen and North to Geleen will decrease. This means that less jobs and businesses are reachable within a certain amount of time for the inhabitants of these areas.

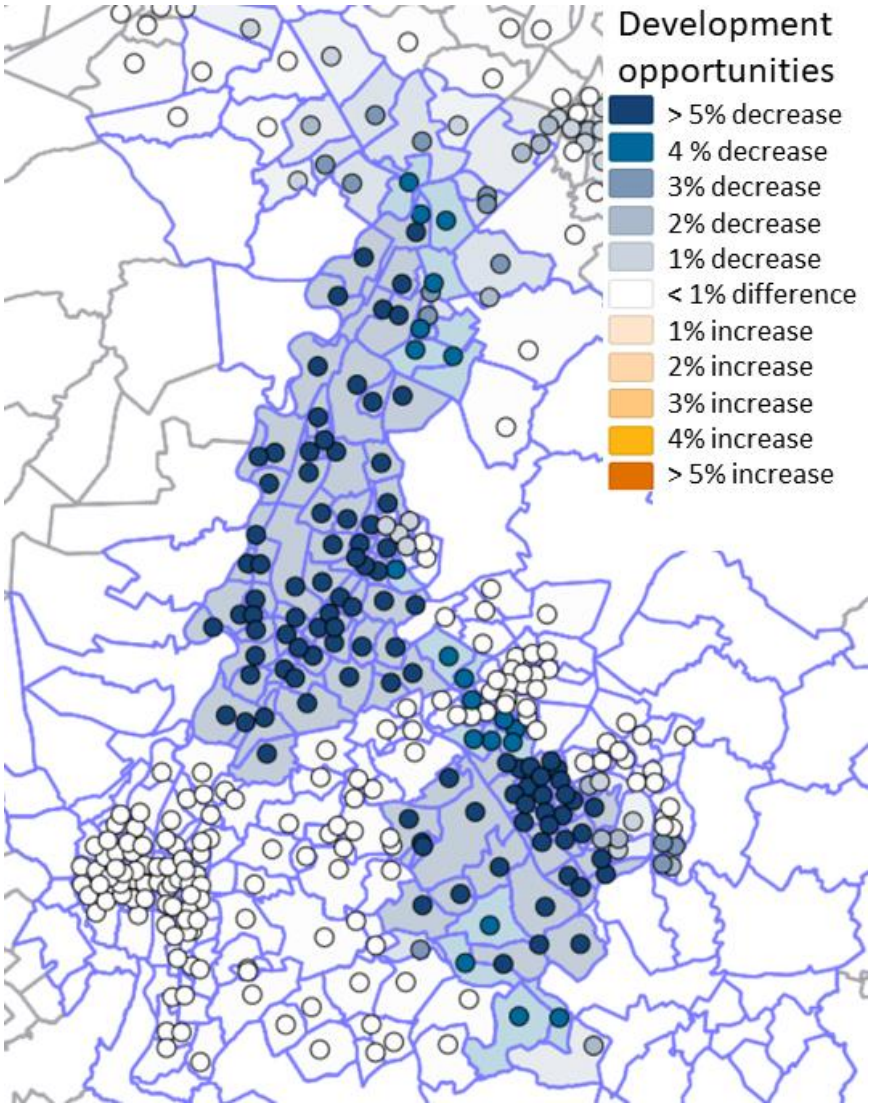

Figure 9: Accessibility difference during road closures (Personal adaptation Mobiliteitsscan, 2023)

7.2. Measures

7.2.1. Assessment measures

In Table 11 is an overview of the assessment of the measures. The measures are sorted with the most effective measures at the top and the least effective measures at the bottom. To determine which measures will be used first the most effective will be implemented and the results will be analysed to determine if more measures are needed. There are two exceptions, the planning of the construction project will be considered first since this is important for the calculations of the other measures. Secondly, the temporary infrastructure is the measure that will be implemented as a last resort if the other measures are not sufficient because it is an expensive measure.

Table 11: Assessment measures

Measure	Safety	Decrease traffic demand	Increase road capacity	Reduce traffic demand during peak hours
Online and social media campaigns	+	+ +	+ -	+
Employers approach	+	+ +	+ -	+
Add temporary infrastructure	+ -	+ -	+ +	+ -
Different planning construction project	+ -	+ +	+	+ -
Set alternative routes Approach for reducing rat running	+ +	+ -	+ -	+ -
Change traffic control scheme	+ -	+ -	++	+ -
Park & ride Encourage the use of public transport	+ -	+	+ -	+ -
Use rush hour avoidance project	+ -	+ -	+ -	+

7.2.2. Effect measures

To determine if the measures have the desired effect, it will be calculated if the bottlenecks are solved. The traffic intensities on the bottlenecks are a worst-case scenario during peak hours. These intensities are only reached if all the traffic that normally travels via the A76 uses the alternative routes. The effects of the measures are in

Measure 1 Planning

The lowest maximum traffic intensities are during the weekend, this is why it is recommended to have the road closures during the weekend. The maximum intensities are 29% lower in comparison to weekdays. This means that having the road closures during the weekend decreases the traffic intensities by 29%. This does not result in a sufficient capacity yet as can be seen in Table 12.

Measure 2 Media campaign + employers approach

The media campaign and employers approach are combined because the effectiveness of these measures is not known individually. The effectiveness combined of the comparable cases was between 25-70%, since this project is more like the project of the A73 maintenance which had a traffic decrease of 50-70% it is assumed that it will result in a traffic decrease of 50% for this project. This results in a sufficient capacity for all bottlenecks (Table 12). To make the measures more robust, and taking into

account that the construction project will take place in 2026 when the traffic intensities are higher there will be one additional measure.

Measure 3 Traffic control scheme

At 4 intersections are traffic lights, at these points the capacity will be increased by 20%, it is assumed that this is possible at all the intersections. This will result in an even larger remaining capacity as can be seen in Table 12.

Table 12: Effect measures

	Direction	Intensity (PCE/h)	Remaining capacity (PCE/h)	After Measure 1 (PCE/h)	After measure 1 + 2 (PCE/h)	After measure 1 + 2 + 3 (PCE/h)
N300-A76 Nuth	N300-A76	3310	-1302	-342	833	1235
	A76-N300	2970	-962	-101	954	1355
A76-A79	A76-A79	1294	881	1257	1716	1716
	A79-A76	1403	772	1179	1677	1677
A76-N281 Simpelveld	A76-N281	2809	-634	181	1178	1178
	N281-A76	2441	-1353	-645	221	439
A79-A2	A2-A79	1210	-730	-379	50	146
	A79-A2	1085	220	535	920	1181
N298-N300	N281-N300	2493	-918	-195	690	1005
	N300-N281	2296	-721	-55	760	1075

7.3. Advice

The measures are put into an advice by selecting the best measures and by explaining this selection. An overview of the advised measures is in Figure 10. The advice to reduce traffic hindrance in the area during the road closures of the Daelderweg and A76 highway is as follows: It is recommended to perform the road closures during the weekend or multiple weekends since this has the lowest maximum traffic intensities per hour. Weekend closures were also used during the A73 maintenance successfully, there is a probability that road users are more likely to change their travel behaviour during a few weekend closures instead of a longer period.

There is an alternative route via the A79/A2 and N300, since the capacity of the reroute via the A79/A2 is limited DRIPs should be used to divide the traffic over the routes and avoid congestion on the A2. Should congestion occur traffic should be sent via the N300 route because in that case, the traffic congestion will occur on the A76 highway which will reduce the hindrance for the other road users that normally travel via the A2. Mobility management needs to be implemented via a social and online media campaign that makes road users aware of the upcoming road closures and presents alternatives. Not only do reroutes need to be promoted, but also the alternative to using public transport since this is a good alternative in the region. The employers approach should be executed together with Zuid-Limburg Bereikbaar, because this organisation has connections in the region and has already been successful in the past. Finally, the traffic light scheme on the routes needs to be optimised so that the traffic on the reroutes has priority, this will increase the capacity of these routes and reduce the chance of delay on the routes. If the delay of the routes is limited the chance of rat running is decreased. Kamp, a road in Nuth may only be used by destination traffic. This is to prevent ongoing traffic of the A76 to use this as a shortcut which will result in congestion in Nuth and decrease the road safety because the road is through a residential area. All these measures combined will reduce the traffic hindrance in the area during the road closures. Making the hindrance short but fierce it is also more likely to get the desired results from the mobility management measures since road users will probably be more willing to travel differently for some short periods instead of a longer period.

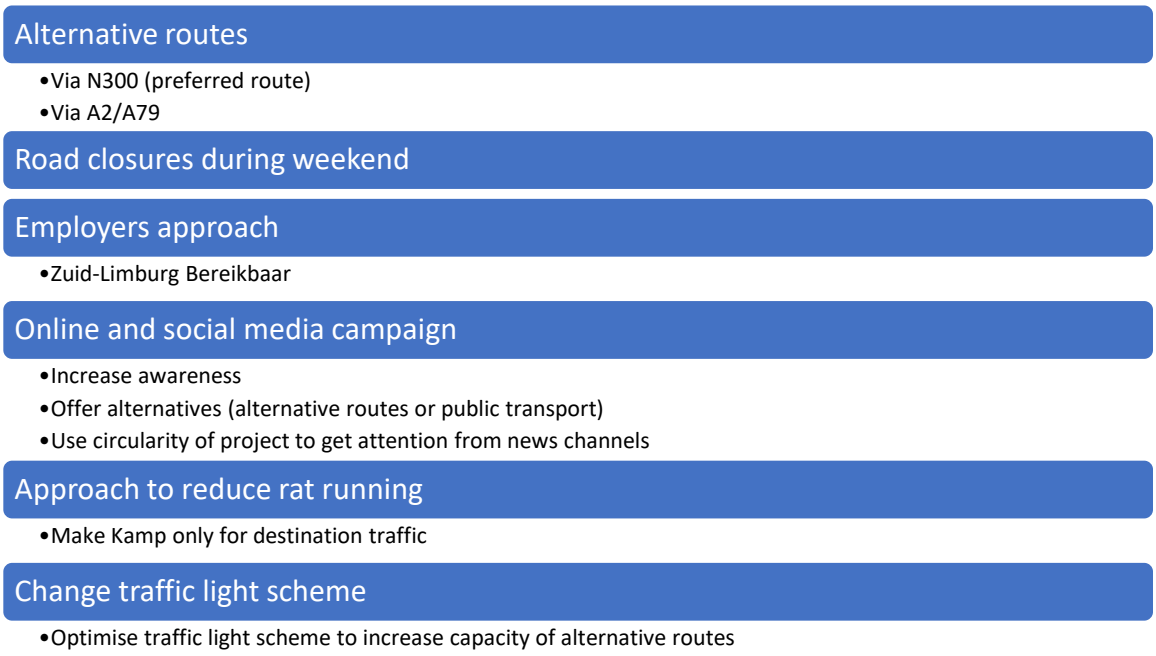

Figure 10: Overview advised measures

8. Discussion

In this chapter, some uncertainties will be discussed. The first point of discussion is the traffic intensities. The intensities that are used in this report are from 2022, in the beginning of this year there were COVID measures which could result in lower intensities. By updating the calculations to the intensities from 2023 the results will be more reliable.

Secondly, it needs to be taken into account that the NRM is a model. A model is not an actual representation of reality which means that road users could behave differently. The NRM network does not contain all roads, and junction delay is only taken into account in a relatively simple manner. This means that the NRM could determine higher intensities on roads than would be possible in reality. Some roads that are not in the model could be on routes that road users will use in reality when there are road closures.

Finally, the effects of some of the measures are assumed to be similar as was found in earlier studies. Yet, as circumstances may differ, the effects of mobility management measures may also differ from previous cases and are thus not completely predictable. It is also not analysed in detail whether it is feasible to change the traffic control schemes on the intersections, to provide additional capacity on alternative routes.

9. Conclusion

The main research question of this thesis is: Which set of measures reduces the traffic hindrance caused by the road closures on the N298 and A76 effectively? This can be answered by the following questions: what is traffic hindrance, what is the traffic hindrance in the area during road construction, how can hindrance be reduced and which measures reduce the traffic hindrance effectively?

Traffic hindrance can be viewed from three perspectives, the road network, the road user and the external effects. This includes the traffic intensities, travel times, delays, safety and accessibility. The delay is the additional travel time a road user experiences due to conditions, incidents and events. Local accessibility means that something is reachable, and there is a possibility to get to the destination. Regional accessibility is focused on quality, it defines how easy something is to reach. Finally, safety is a necessary precondition. To ensure road safety roads must be used for their intended function.

During the road closures, it is required to reroute via the main road network. During the closure of the A76 and Daelderweg there are two options: one via the A2/A79 and one via the N300. To determine the traffic hindrance during road closures the effects on these alternative routes are determined. The result is that there is still sufficient capacity left on the road network if the road closures take place during the weekend. Since the capacity of the intersections is lower the remaining capacity of the bottlenecks is also calculated. When all the through traffic of the A76 uses the alternative routes the capacity is insufficient. Other conclusions from the traffic analysis show that rat running is decreased if the delay on the alternative routes is limited. Finally, the accessibility of the Parkstad region decreases during the road closures, especially around Heerlen and Sittard-Geleen.

In order to reduce this hindrance, Rijkswaterstaats Minder Hinder approach is used. This approach is divided into Smart Planning, Smart Building and Smart Travel. The main focus is on reducing the hindrance for all road users and other stakeholders. Safety is a precondition and accessibility needs to be maintained.

Finally, the measures that reduce the traffic hindrance caused by the road closures on the N298 and A76 effectively are as follows. The road closures need to take place during the weekend, there needs to be a social media and online campaign which informs the road user about the upcoming road closures and suggests alternatives. The employers approach needs to be executed via Zuid-Limburg Bereikbaar and traffic lights should be optimised to give priority to the alternative routes. Finally, Kamp, a road in Nuth may only be accessible for local traffic to prevent rat running and ensure the accessibility of the business park in Nuth. Together these measures will result in a limited delay on the alternative routes and as a result, reduce the hindrance caused by the road closures.

10. Recommendation

In this chapter is a recommendation for further research. The traffic analysis was performed using the NRM. This model does not have all regional or local roads implemented which means that the effects of the road closures on the underlying road system are only slightly visible. Further research could use a regional model of the municipality or province that will give a more detailed result of the traffic allocation during road closures. It will help to see the effects of the closure of the N298 and it can be used to determine if additional measures are needed to prevent rat running or to prevent safety issues.

The possibilities of changing the traffic control scheme are also interesting for further research. In this thesis it is assumed that the capacity can be increased by 20%, this could be more or less in reality. The road authority manages these traffic lights and is also responsible for changing the traffic control scheme during road closures.

The only scenario that is researched in this thesis is a complete closure of the A76 highway, further research could try different scenarios. For example, a scenario where one lane in each direction remains open.

Finally, further research could focus on the effects of the construction project on the A2 highway Vonderen - Kerensheide. The rush hour lane will be transformed to a normal lane, during this project there will be 2x3 lanes available as much as possible, but there will be speed limitations. This will probably also impact the traffic intensities on the A76 highway, further research could analyse what these effects are and if it is possible to combine mobility management measures to reduce hindrance for both construction projects.

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Appendix

Appendix A : traffic analysis

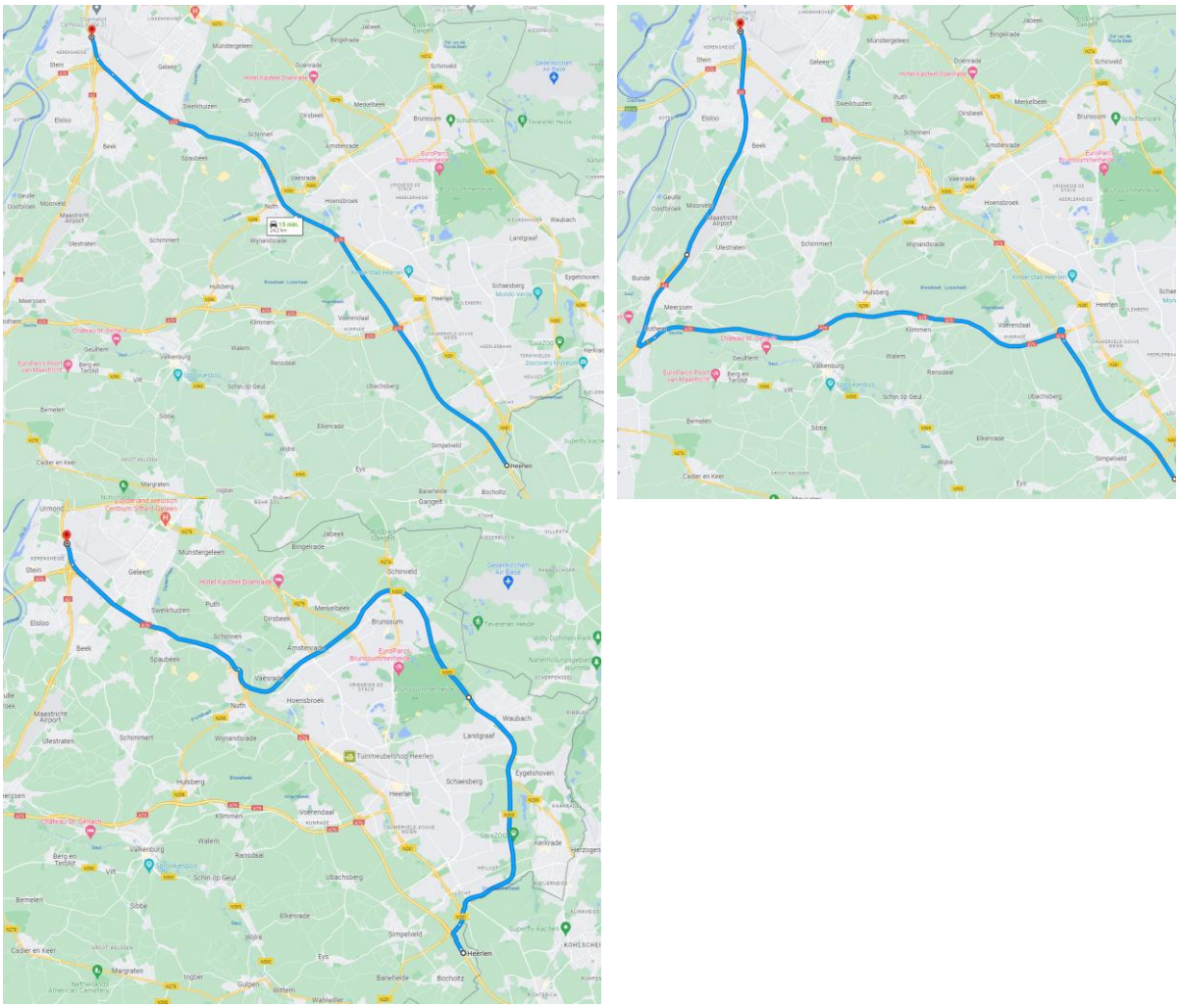
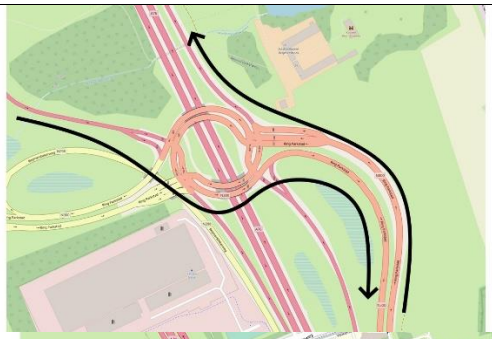
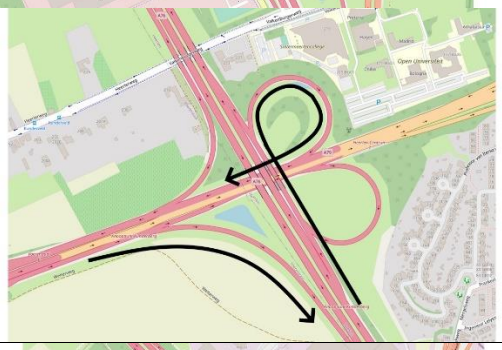
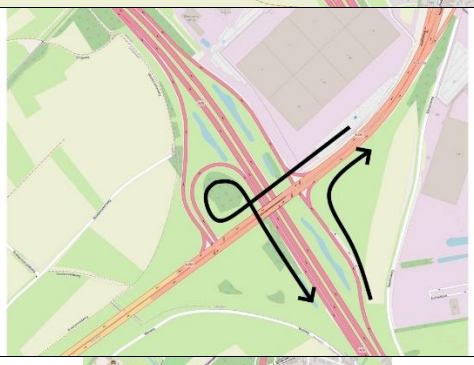
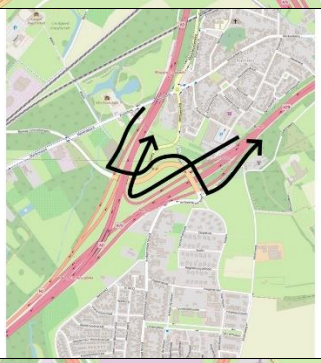


Figure 11: overview alternative routes(Google Maps, n.d.)

Table 13: overview bottlenecks

Bottlenecks	
1	
2	
3	
4	
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