Promoting Road Safety Between Automated Vehicles and Cyclists

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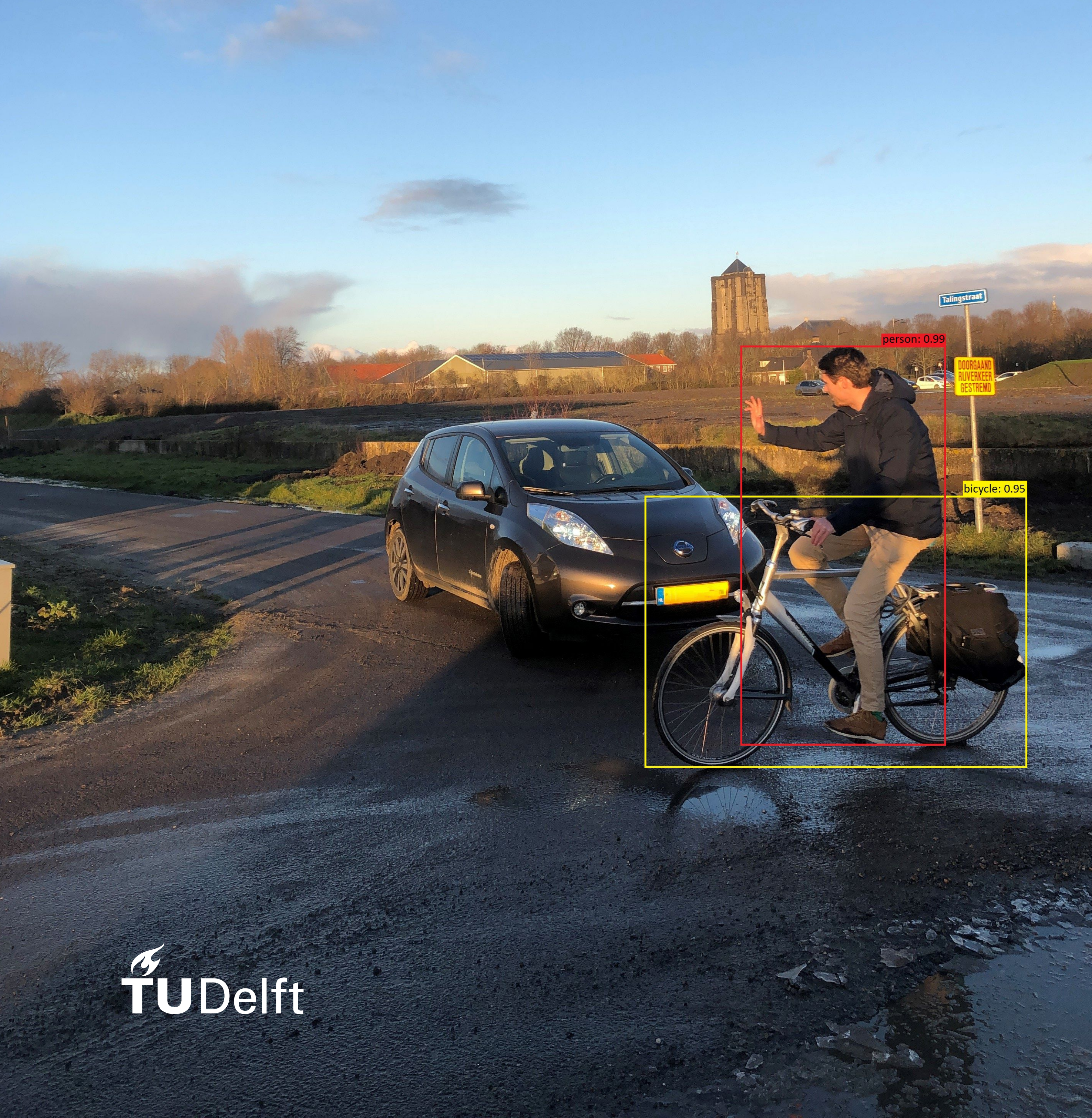

TU Delft

Promoting Road Safety Between Automated Vehicles and Cyclists

by

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Please, enjoy reading!

Tim Vleeshouwer
Zierikzee, January 2021

Table of Contents

List of Figures

List of Tables

List of Abbreviations

ADS Automated Driving System

AV Automated Vehicle

BAC Blood Alcohol Concentration

BMV bicycle-motor vehicle

BRON Bestand geRegistreerde Ongevallen in Nederland

DDT Dynamic Driving Task

E-HMI External Human Machine Interface

ER Emergency Room

HDV Human Driven Vehicle

HMP hectometer post

LIDAR Light Detection and Ranging

ODD Operational Design Domain

OEDR Object and Event Detection and Response

OEM Original Equipment Manufacturer

PNH Provincie Noord-Holland

RADAR Radio Detection and Ranging

SAE Society of Automotive Engineers

SiN Safety in Numbers

SWOV Stichting Wetenschappelijk Onderzoek Verkeersveiligheid

VRU Vulnerable Road User

Executive Summary

Automated Vehicles (AVs) gain more and more attention and are becoming increasingly reliable every year. Where other countries make big steps forward towards highly automated vehicles, the Netherlands is losing its top-ranked position in the world of AVs. The great number of cyclists contributes significantly to creating a challenging environment for AVs, especially in urban areas dominated by cyclists. Although the number of studies focusing on AVs interacting with vulnerable road users is increasing, there is an enormous research gap specifically focusing on cyclists. The situation in the Netherlands is unique as no other country comes close in terms of bicycle use. To maintain this favorable position of cyclists in the Netherlands, it is important that the presence of AVs does not decrease cyclist safety. To determine how to promote safety between AVs and cyclists, the following main research question was formulated: *"How to promote road safety between SAE-level 4 Automated Vehicles and cyclists in mixed traffic environments outside city limits?"*. By answering the sub-research questions, the key findings of this research are presented in this summary.

The Situation Awareness theory by Endsley (1995) is used throughout this study as an important basis for road safety. For AVs, this Situation Awareness is created by object detection, classification, and trajectory prediction (Table 1). To safely interact with cyclists, all three levels of Situation Awareness need to be sufficiently accurate. If either cyclist detection, classification, or trajectory prediction is incorrect, Situation Awareness is reduced, potentially resulting in dangerous situations.

Table 1: Different levels of Situation Awareness for human drivers and Automated Vehicles

	Human drivers (Endsley, 1995)	*Automated Vehicles*
Level 1	Perception of the elements in the environment	Object detection
Level 2	Comprehension of the current situation	Object classification
Level 3	Projection of future status	Object trajectory prediction

Determinants Affecting Road Safety Between Automated Vehicles and Cyclists

The first sub-research question was: *"Which determinants affect road safety between Automated Vehicles and cyclists?"* An elaborate literature review was conducted to identify a broad range of determinants influencing road safety between AVs and cyclists. The results are structured in a conceptual framework based on Schepers et al. (2017), as presented in Figure 1. Next to the direct relation between AVs and cyclists, the interaction with other road users and road infrastructure is important. The combination of these factors leads to the risk of serious and fatal accidents between cyclists and AVs. The actual number of accidents is determined by the combination of this accident risk and the exposure of cyclists to AVs.

Many determinants affecting road safety are identified, the most important of which are mentioned in Figure 1. From the perspective of cyclists, some determinants negatively influence the risk of accidents. Examples of these determinants are informal cyclist behavior, cyclists violating the law, and non-homogeneous behavior of different cyclist types. Additionally, it is expected that cyclists will adapt their behavior when interacting with AVs instead of HDVs (Human Driven Vehicles). However, the exact implications are yet unknown. From the perspective of the road infrastructure, a good quality and clear cycling infrastructure are found to positively influence cyclist safety. Furthermore, street lighting ensures increased cyclist detection. From the perspective of AVs, it is found that cyclist detection is not yet sufficiently accurate. Furthermore, it is difficult to accurately predict cyclist intentions, which is also the case for human drivers.

As AVs will not always be recognized by cyclists, cyclists sometimes will respond to AVs as they would respond to HDVs. Additionally, incorporating positive driver behavior towards cyclists, resulting from cycling experience and infrastructure familiarity, can increase safety by having more conservative settings. Finally, segregating cyclists from AVs will decrease exposure and thereby the probability of accidents.

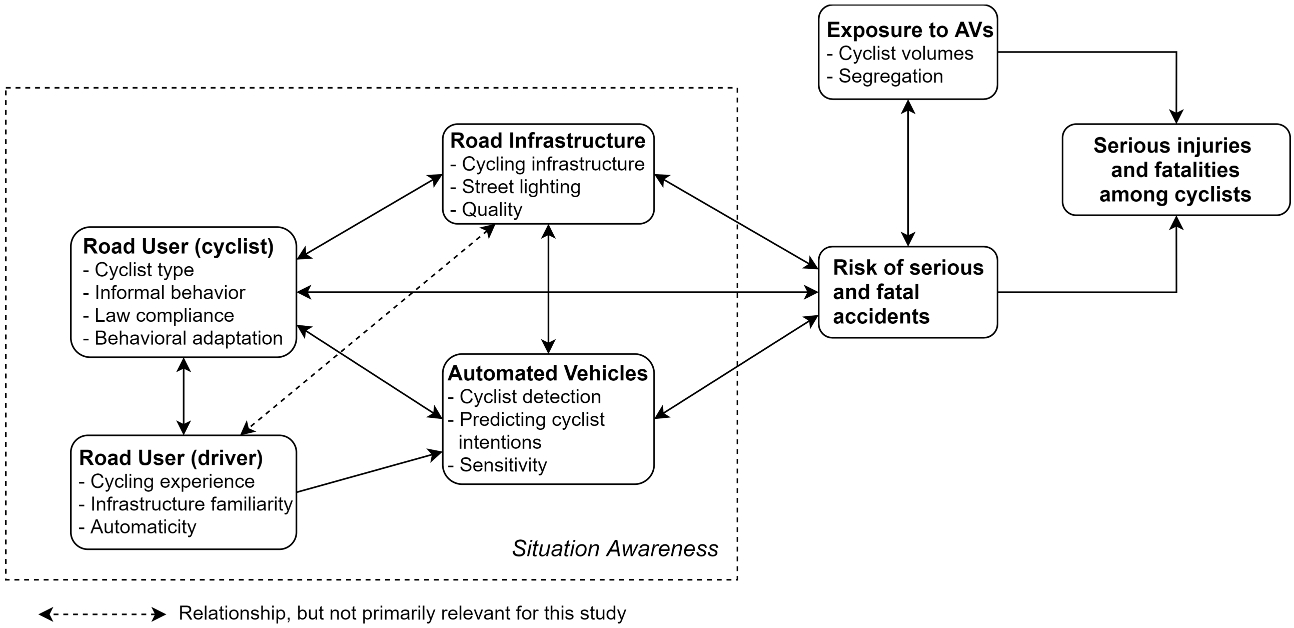


Figure 1: Conceptual framework on factors affecting road safety between AVs and cyclists, including the most important determinants

Surrogate Measures of Safety to Assess Road Safety

As SAE-level 4 AVs do not yet share the road with cyclists in the complex cycling environment in the Netherlands, assessing road safety between AVs and cyclists is not straightforward. To explore the possibilities to assess safety, the second sub-research question was: *"Which Surrogate Measures of Safety can be used to assess road safety between Automated Vehicles and cyclists?"* This was executed by identifying Surrogate Measures of Safety that are currently used to assess road safety between cyclists and motor vehicles. Based on the characteristics of AVs, the most relevant Surrogate Measures of Safety are taken into account. Each Surrogate Measure of Safety was translated to an interaction scenario between AVs and cyclists, and definitions were given accordingly. Two were added because they are specifically interesting for AVs: *'visual communication required'* and *'cyclist detection accuracy'*. If visual communication with cyclists is required to achieve a safe interaction, it will be challenging for an AV. Furthermore, cyclist detection accuracy needs to be sufficient before sharing the road with cyclists. An overview of Surrogate Measures of Safety to assess road safety between AVs and cyclists is given in Table 2.

Table 2: Overview of Surrogate Measures of Safety to objectify road safety between AVs and cyclists

Surrogate Measure of Safety	**Definition**
Degree of segregation	The way in which cyclists are segregated from vehicles
Vehicle speed	The speed that an AV drives at a conflict situation
Cyclist traffic volume	The number of cyclists per hour at the busiest time of day
Predictability of behavior	The extent to which the conflict situation facilitates predictable cyclist behavior
Visibility	The extent to which the conflict situation can clearly be overseen
Infrastructure clarity	The extent to which the infrastructure is clear and recognizable
Visual communication required	The extent to which visual communication is needed to achieve a safe interaction
Cyclist detection accuracy	The ability of an AV to accurately detect and classify cyclists
Cyclist traffic violations	The extent to which the conflict situation facilitates cyclist traffic violations

Initially, '*cyclist violations'* was not identified as Surrogate Measure of Safety. However, during the expert interviews, many experts mentioned cyclist violations to be an important risk factor to take into account. Therefore, *'cyclist violations'* is added. An important note that needs to be made is that not every Surrogate Measure of Safety is unambiguously quantifiable. Subjective elements are present when e.g. determining the extent to which a situation is sufficiently clear and recognizable, or whether a situation facilitates cyclist traffic violations or not. Table 3 presents an overview of how to objectify the safety level for each Surrogate Measure of Safety.

Risk Factors for Cyclist Safety

The third sub-research question was: *"To what extent is the road infrastructure network in the province of Noord-Holland (the Netherlands) ready for a safe interaction between Automated Vehicles and cyclists?"* Based on the Surrogate Measures of Safety, potential conflict situations are identified. These situations were presented to Dutch experts in the field of AVs and cyclists, to identify the main risk factors for road safety between AVs and cyclists. It was evaluated that too many risk factors were present at road sections if cyclists and vehicles were not physically segregated. For the remainder of the analysis, it was therefore taken as a requirement that road sections need to be physically segregated, limiting the conflict situations to junctions. Another requirement is related to *'cyclist detection accuracy'*: it needs to be ensured that cyclists are accurately detected and classified by AVs before AVs are permitted to drive in mixed traffic environments. Based on the expert interviews, a classification of the remaining Surrogate Measures of Safety is made. Each Surrogate Measure of Safety is distinguished into three different safety levels:

- *Adequate*: Safety level is sufficient for AV/cyclist interaction
- *Point of attention*: Safety level leads to minor risks in cyclist safety
- *Problem area*: Safety level leads to major risks in cyclist safety

An overview of the classification of Surrogate Measures of Safety with corresponding attributes for each safety level is presented in Table 3.

Table 3: Classification of Surrogate Measures of Safety to assess road safety at junctions

Surrogate Measure of Safety*	**Adequate**	**Point of attention**	**Problem area**
Vehicle speed	<50 km/h	50 – 80 km/h	>80 km/h
Cyclist traffic volume	Low; Medium	High	
Predictability of behavior	Signalized intersection; Priority intersection (cyclists having priority)	Priority intersection (AVs having priority)	Non-priority intersection; Shared space
Visibility	Clear overview of conflict situation and cyclist trajectory path	Conflict situation or cyclist trajectory path could be (partly) occluded	Conflict situation or cyclist trajectory path (partly) occluded
Infrastructure clarity	Good quality of road surface markings and situation is according to CROW guidelines	Deteriorated quality of road surface markings or missing road signs	Situation is not according to CROW guidelines; No standard (trained) situation
Visual communication required	Seldom: design of infrastructure does not facilitate visual communication	Sometimes: design of infrastructure facilitates visual communication in certain specific scenarios	Often: purpose of infrastructure is to communicate
Cyclist traffic violations	Seldom: infrastructure facilitates almost no violations	Sometimes: infrastructure facilitates occasional violations	Often: infrastructure facilitates violations (consciously or unconsciously)

**Degree of segregation and cyclist detection accuracy are not included, as these are taken as a requirement for road safety: road sections must be physically segregated and cyclists need to be accurately detected and classified by AVs*

To determine the infrastructure readiness of the road infrastructure network in the province of Noord-Holland, the rubric in Table 3 is used to assess road safety of conflict situations. In total, slightly over 25% of provincial roads managed by the Provincie Noord-Holland is analyzed by virtually going over each road. As data on cyclist traffic volumes were not available for the majority of conflict situations, this is not taken into account for the analysis. The results show that the difference between provincial roads is large in terms of conflict situations and problematic situations. Although some of the identified accident risk factors are also present for HDVs, these are considered to be a larger problem for AVs based on the expected characteristics of AVs. Common identified accident risk factors are as follows:

Problem areas

- *Visibility* - Multiple situations are identified with a (partly) occluded cyclists' trajectory path, reducing visibility and thus Situation Awareness
- *Infrastructure clarity* - Two situations are found with conflicting priority rules: although road surface markings indicated a priority intersection, the situations are regulated by traffic lights, possibly leading to confusion
- *Predictability of behavior* - To account for the highly specific traffic scenario with many different road users close to the beach at the N200, it was decided to deviate from standard infrastructure guidelines. Infrastructure design suggests a shared space, leading to difficult to predict cyclist behavior, including visual communication and possible cyclist traffic violations

Points of attention

- *Visual communication required* - The relatively low vehicle speed when entering roundabouts where cyclists do not have priority, especially if congested, facilitates visual communication and informal behavior
- *Cyclist traffic violations* - Infrastructure design sometimes facilitates occasional cyclist traffic violations, such as roundabouts where cyclists do not have priority or single-lane intersections, due to the short crossing distance
- *Infrastructure clarity* - Infrastructure was sometimes marked as unclear due to missing road surface markings to indicate a cyclist crossing

Promoting Road Safety Between Automated Vehicles and Cyclists

To come up with needs to promote road safety, the fourth sub-research question was: *"What are the needs to promote road safety between Automated Vehicles and cyclists, from the perspective of the AV and the road infrastructure?"* Based on the identified accident risk factors, methods to promote road safety are presented. It is essential to realize that risk factors do not necessarily lead to accidents. However, the challenges for AVs to safely deal with such situations are increased. To guarantee cyclist safety, cyclists should be segregated from AVs to limit exposure. As that is not always possible in the current road infrastructure network, exposure between AVs and cyclists should be limited. Limiting exposure leads to limited conflicts, limited serious conflicts, and thus limited accidents. In the initial Operational Design Domain (ODD) for SAE-level 4 AVs, continuous conflicts should be avoided: i.e. situations where AVs and cyclists are continuously exposed to each other. In the remaining conflict situations at junctions, there is always some exposure. Similar to interaction scenarios between cyclists and HDVs, exposure lead to risks. Minimizing these risks will increase road safety. For each Surrogate Measure of Safety, the most important findings to minimize these risks and thus promote road safety are presented in Table 4.

Table 4: Methods to promote road safety between Automated Vehicles and cyclists

Surrogate Measure of Safety	**Methods to promote road safety**
Degree of segregation	Continuous conflicts should be avoided, therefore cyclists should be physically segregated from AVs at road sections
Vehicle speed	Lowering vehicle speeds at conflict situations where cyclists could be encountered, ensures a reduced cyclist fatality rate in case of an accident due to lower impact speeds
Cyclist traffic volume	Collecting cyclist traffic volume data gives more insight in which junctions have a large exposure
Predictability of behavior	Signalized intersections are preferred due to the regulated situation. Intelligent traffic lights should be used to communicate with AVs, and intersections with increased risk should be identified e.g. based on cyclists' red-light running numbers.
Visibility	Conflict situations with a (partly) occluded cyclists' trajectory path should be adjusted or excluded from the initial ODD
Infrastructure clarity	Infrastructure should be according to CROW guidelines to ensure recognizability, and road surface markings should be present at locations where cyclists could cross to increase Situation Awareness
Visual communication required	More knowledge of the exact implications for cyclist safety is needed for the specific interaction scenarios where visual communication is facilitated
Cyclist detection accuracy	Before AVs are permitted to drive in mixed traffic environments, cyclist detection accuracy should be sufficient
Cyclist traffic violations	More knowledge of the exact implications for cyclist safety is needed for the specific interaction scenarios where cyclist traffic violations are facilitated

Recommendations for Future Research

This research aims to be a starting point towards more attention for cyclists during the development of AVs. The results of the current work present an overview of accident risk factors that should be taken into account, either from the perspective of the AV or the road infrastructure. Much work has to be done in order to further promote safety between AVs and cyclists. Based on the limitations of this work and the needs for promoting safety, some recommendations for future research are as follows:

- **Improve Situation Awareness towards cyclists**
  Currently, AV technology is considered to be not yet sufficiently advanced in terms of detection capabilities. One of the requirements for road safety is that all three levels of Situation Awareness should be correct: i.e. cyclist detection, classification, and trajectory prediction. Future research should focus on developing AV technology to improve the detection and classification of cyclists. It is important to guarantee accurate detection in many diverse situations, such as in adverse weather conditions, during darkness, and with sun glare. The Dutch Vehicle Authority (RDW) must formulate requirements on how to determine whether an AV is sufficiently safe to be permitted in mixed traffic environments.

  Another research direction to improve Situation Awareness is understanding cyclist behavior, which is essential for correct trajectory prediction. More information on the behavioral adaptation of cyclists towards AVs is desired, as the exact implications are yet unknown. Additionally, understanding the differences in behavior based on cyclist type can be useful. If the differences in the behavior of different cyclist types are better known, this can be used in supervised learning for AV algorithms to improve trajectory prediction.

  Improving Situation Awareness also goes the other way around: research to come up with reliable and understandable External Human Machine Interfaces should continue, to communicate the intentions of AVs to cyclists.

- **Analyze problematic scenarios in more detail**
  The presented accident risk factors and conflict situations are based on subjective and qualitative assessment of the Surrogate Measures of Safety. An important next step is to quantify the safety levels, to be able to objectively determine whether a conflict situation is sufficiently safe or not. Especially for the problematic scenarios (such as the *'problem areas'* in the rubric of Table 3), more information is needed. Therefore, certain scenarios need to be analyzed in more detail, including but not limited to:

  - Situations with reduced visibility, to determine the implications for cyclist detection
  - Situations facilitating visual communication, to understand the challenges of informal behavior, e.g. at roundabouts where cyclists do not have priority
  - Situations facilitating cyclist violations, to determine the severity of these violations, e.g. at single-lane crossings and roundabouts where cyclist do not have priority
  - Situations with unclear road surface markings, to determine if changes are needed

  It is important that all aspects of an interaction scenario are taken into account, e.g. from the perspective of cyclists, AVs and the road infrastructure. Therefore, collaboration between road authorities, Original Equipment Manufacturers (OEMs), and the cycling industry is preferred.

- **Train Automated Vehicles in specific Dutch situations**
  Multiple accident risk factors and problematic infrastructure situations are presented in this research. However, this does not necessarily mean the risks are too large for a safe interaction. Unfortunately, accidents will happen in traffic. A future research direction for OEMs is to convince that their system is able to cope with the risks in a safe way. Therefore, it is important that AVs are trained in situations with cyclists. As the Dutch cycling environment is significantly different from other countries, it is evident that AVs are trained in specific Dutch situations. In the province of Noord-Holland, pilots can be held on specific roads based on the results of the infrastructure readiness analysis. Road sections can be selected based on the type of conflict situations, and their present attributes for each Surrogate Measure of Safety. During these pilots, it is essential that the safety of other road users is ensured. This again highlights the importance of collaboration between road authorities and OEMs.

1 Introduction

The technology of Automated Vehicles (referred to as AVs) is improving rapidly, and reliable Automated Vehicles are closer to reality than ever. Recently, Tesla released its self-driving beta in the United States for some of its users (Musk, 2020). Furthermore, Waymo opened its driverless ride-hailing service in Phoenix, Arizona, for a select number of users (Waymo, 2020). Although these are still pilots, it looks promising towards a future of automated driving. However, an important safety note needs to be made. During testing, AVs have been present in multiple accidents, sometimes even leading to fatalities. An example is an accident in Arizona, 2018, where an Uber test vehicle collided with a pedestrian, leading to the fatality of the pedestrian (NTSB, 2019a). It is extremely important that the introduction of AVs does not lead to a decrease in other road users' safety.

In 2019, the Netherlands was ranked number one in the Autonomous Vehicle Readiness Index of KPMG (2019). Especially the infrastructure quality, consumer acceptance, and experimental law for self-driving vehicles is said to contribute to this position. There is however a large challenge for the widespread adoption of AVs in the Netherlands: cyclists. KPMG (2019) concludes that due to cyclists: *"in urban, crowded areas it will be very difficult to start autonomous driving"* (p. 14). The introduction of AVs must not lead to a decrease in cyclists' safety, and therefore AVs must be able to safely interact with cyclists. For the previously mentioned pilots of Tesla and Waymo, this is no large issue due to the absence of cyclists. However, the complexity of cyclist behavior makes this a truly difficult challenge for countries with large cyclist volumes.

Dutch cycling environment The cycling environment in the Netherlands is unique to the rest of the world. In 2019, a total of 4.8 billion bicycle trips were made, covering 17.6 billion kilometers (de Haas & Hamersma, 2020). This corresponds to an average of 3.0 kilometers per person per day. For all trips made, the modal share of bicycles is 28%, coming close to the 35% of vehicles (de Haas & Hamersma, 2020). An interesting fact is that there are more bicycles than inhabitants in the Netherlands. On average there are 1.3 bicycles per inhabitant, significantly exceeding the rest of the world (van Es, 2019). The downside of the tremendous bicycle use in the Netherlands is the number of cyclists involved in accidents. An overview of the number of cyclist fatalities and total road fatalities in the Netherlands over the past years is presented in Figure 1.1. Although the number of total fatalities in road accidents has been decreasing, the number of cyclist fatalities has been fairly constant over the years. The large majority of these cyclist fatalities result from bicycle-motor vehicle (BMV) accidents (Reurings et al., 2012). To reduce the number of cyclist fatalities, vulnerable road users are an important aspect of infrastructure design (SWOV, 2018).

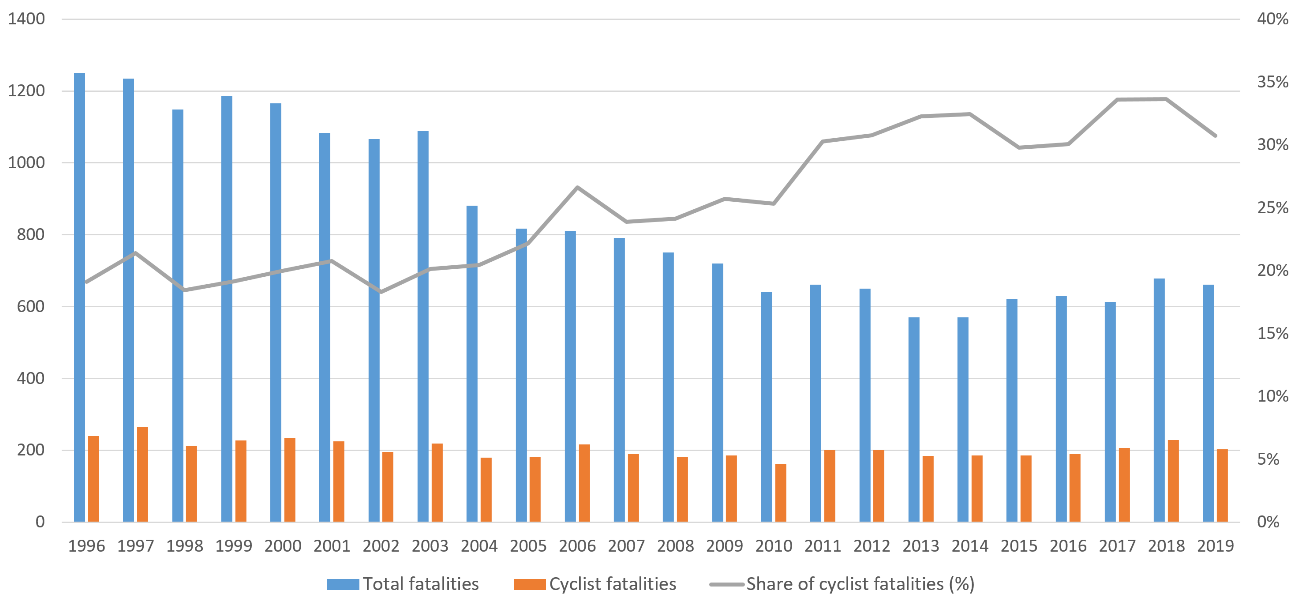


Figure 1.1: Share of cyclist fatalities in Dutch road accidents (data retrieved from CBS (2020))

Potential of Automated Vehicles for traffic safety In total, over 90% of traffic accidents can be attributed to human error (Treat et al. (1979); Khattak et al. (2021)). This human error is also found as a main cause for BMV accidents, and often there is a combination of both unsafe behavior of the cyclist and the other road user (SWOV, 2017). Examples of frequently observed unsafe behavior of other road users are speeding, distraction, red-light running, and driving under the influence (Mesken, 2012). Automated Vehicles have the potential to improve traffic safety, as these causes for unsafe behavior are mostly related to erroneous actions caused by human characteristics. Some human characteristics and their contribution to the occurrence of traffic accidents and injuries are presented by (SWOV, 2018, p.11):

- People occasionally make errors, even if they are well trained, informed or educated
- People's concentration span is limited and they are not always conscious of their behavior and choices and of their consequences, in particular when they are inexperienced or impaired
- People can only process certain amounts of information simultaneously and will get tired after a while
- People easily create connections between their daily experiences, so that they may develop a different perception of reality and risks than what objective information reveals
- People regularly behave based on motives that are not necessarily ideal for the safety of themselves or those around them

As these characteristics are inherent to humans, there will always be a lack of road safety. This means that Automated Vehicles have a significant potential to reduce the risk of road accidents, thereby increasing traffic safety.

Challenges of Automated Vehicles interacting with cyclists On the other hand, there are also some human characteristics that contribute to the prevention of traffic accidents and injuries, such as (SWOV, 2018, p.11):

- People have the ability to learn and to adapt. They relatively easily adjust to new circumstances
- People are creative and inventive, including when they encounter unfamiliar problems

It is important that the benefits of these human characteristics are not lost with the introduction of AVs. Adjusting to new circumstances and responding to unfamiliar problems is difficult for AVs. Parkin et al. (2016) provide an example of an AV standing still for several minutes because a cyclists' intention could not accurately be predicted.

Furthermore, there are additional challenges for AVs, especially when interacting with cyclists. Challenges are among others related to detection, communication, and prediction of intentions (Sandt & Owens, 2017). Botello et al. (2019) concluded that current cyclist detection capabilities of AVs are not sufficient, especially during the night or in adverse weather conditions. Furthermore, Ahmed et al. (2019) stated that cyclist detection is more difficult than pedestrian detection, caused by greater variability in possible orientations. Communication is another challenge for AVs, as this is an important aspect of current vehicle-cyclist interactions (Vissers et al., 2016). Vissers et al. (2016) stated that it will especially be difficult for AVs to read informal communication cues of cyclists, as these are subtle and not unambiguous. Finally, intention prediction is a challenge for AVs. For human drivers, it is already very difficult to predict cyclist intentions (Westerhuis & de Waard, 2017). The difficulty of intention prediction increases with unpredictable or unsafe cyclist behavior: e.g. using a smartphone while cycling, cycling under the influence, or cycling without proper bicycle lights (SWOV, 2017).

1.1 Research Questions

It is evident that the potential of Automated Vehicles to increase traffic safety is large. However, many effects are still to be explored in greater detail, such as the implications for vulnerable road users. Although the number of studies focusing on AVs interacting with vulnerable road users is increasing, it is not yet fully explored to determine the implications on traffic safety. This is also advocated by Hagenzieker et al. (2020, p. 96): *"It is important to explore and define decision-making processes and behaviour of cyclists in the transition period when road traffic consists of automated and manually driven cars, explicitly taking the perspective of the cyclist"*. Especially research focusing on cyclist safety is lacking, as most of the studies focus on pedestrian safety. This is logical, as the Netherlands and Denmark are the only two countries where the number of cycling trips exceeds walking trips (Buehler & Pucher, 2012).

However, the large amount of cyclists in the Netherlands enlarges the challenge for AVs to safely interact with vulnerable road users. Especially in city centers, bicycles are used for most of the trips, often encountering motor vehicles. This is also seen in the large difference in bicycle-motor vehicle (BMV) accident numbers within and outside city limits. Based on current BMV accident details and exposure, it would be probable to first permit AVs on roads where exposure to vulnerable road users is minimal. From a safety point of view, AVs should preferably be segregated from cyclists. However, as that would significantly reduce the possibilities for AVs in the Netherlands, it is desired to explore the implications on traffic safety for mixed traffic environments.

The exposure to vulnerable road users is highest in city centers, and therefore the focus will be outside city limits. Outside city limits, cyclists are often physically segregated from the carriageway. This is not possible at every conflict situation, as this requires a lot of costly changes to the current infrastructure. Therefore, a mixed traffic environment will always remain, meaning that AVs need to take into account cyclists to ensure their safety. To maintain the favorable position of cyclists in the Netherlands, it is important that the presence of AVs does not result in a decrease in cyclist safety or subordination of the position of cyclists.

The main research question is formulated as follows:

How to promote road safety between SAE-level 4 Automated Vehicles and cyclists in mixed traffic environments outside city limits?

The following sub-research questions are formulated to answer the main research question:

1. Which determinants affect road safety between Automated Vehicles and cyclists?
2. Which Surrogate Measures of Safety can be used to assess road safety between Automated Vehicles and cyclists?
3. To what extent is the road infrastructure network in the province of Noord-Holland (the Netherlands) ready for safe interaction between Automated Vehicles and cyclists?
4. What are the needs to promote road safety between Automated Vehicles and cyclists, from the perspective of the AV and the road infrastructure?

Sub-research question 1 aims to give a comprehensive overview of determinants affecting road safety between AVs and cyclists. The main goal is to explore what is of importance in this interaction and to identify factors that could be detrimental to cyclist safety. The scientific contributions in literature related to the determinants found will be discussed. The results of this sub-research question will be used as a theoretical background as a basis for the rest of this study.

Sub-research question 2 aims to find a way to assess road safety between AVs and cyclists. As AVs and cyclists do not yet share the roads, at least not in the complex cycling environment in the Netherlands, determining safety is not straightforward. Therefore, Surrogate Measures of Safety are explored to take into account possible future threats when AVs and cyclists are to operate in a mixed traffic environment. Based on the Surrogate Measures of Safety, situations that could potentially lead to conflicts between AVs and cyclists are presented.

Sub-research question 3 aims to present a methodology to assess road safety of potential conflict situations between AVs and cyclists. With this method, (part of) the road infrastructure in the province of Noord-Holland in the Netherlands will be analyzed. Conflict situations will be identified in order to determine the risk factors leading to potentially hazardous situations.

Sub-research question 4 aims to give an overview of the challenges for road safety between AVs and cyclists. Based on these challenges, both road authorities and Original Equipment Manufacturers (OEMs) can determine what is in their power to reduce the impacts of these risk factors and thereby increasing safety. Some suggestions and focus points on how to promote road safety will also be presented.

1.2 Scope of this Research

This research aims to explore road safety between AVs and cyclists from a broad perspective. Some focus points determining the scope of this research are discussed in this section.

Dutch cycling situation The focus is on the Dutch cycling situation. In the Netherlands, the cycling environment is unique compared to the rest of the world, resulting in a high level of cyclist safety (Schepers et al., 2017). The Netherlands by far exceed other European countries in terms of bicycle use (TNS Opinion & Social, 2014), and only Denmark has similar safety levels per kilometer cycled (Buehler & Pucher, 2020). The Dutch government actively focuses on making the Netherlands even more bicycle-friendly, both for the environment and to improve people's health (Rijksoverheid, 2020). This results in a cycling situation that is not comparable to other countries.

Roads outside city limits As stated in the research question, the focus is on roads outside city limits. The Provincie Noord-Holland is the road authority on many of these roads, making the results more relevant. Furthermore, due to the complexity of traffic situations within city limits, it is expected that AVs will first only be allowed on roads with minimal exposure to vulnerable road users.

SAE-level 4 Automated Vehicles The term 'Automated Vehicle' is used for many different types of automation, ranging from driver assistance to fully autonomous and driverless. In this study, the term 'Automated Vehicle' is used for high driving automation, referred to as 'Level 4 Automated Vehicles' according to the classification of the Society of Automotive Engineers (SAE International, 2018). In literature, 'Autonomous Vehicles' is frequently used to describe such vehicles. As this incorrectly suggests the automated driving system is self-governing (SAE International, 2018), the term 'Automated Vehicle' is used in this study. SAE International (2018) distinguished two types of level 4 Automated vehicles: driverless ('ADS-dedicated vehicle') and with a passenger ('dual-mode'). This study assumes there is a passenger in the AV to take over outside the Operational Design Domain (ODD). Although the focus is on dual-mode AVs, passengers are not required to be fallback-ready, and the results are thus also highly applicable to driverless AVs ('ADS-dedicated vehicles').

SAE-level 4 automation is chosen, as that is the first level where the driver is not expected to respond to a request to intervene. In SAE-level 3 automation, the driver is fallback-ready and becomes the driver during fallback. When interacting with cyclists, this means the Automated Vehicle is not always responsible. The receptive fallback-ready user performs fallback e.g. if recognizing vehicle failure or responding to a request to intervene. From SAE-level 4 onwards, the Automated Vehicle is always responsible within a predefined ODD, meaning encountered cyclists should be handled in a safe manner by the Automated Vehicle. The focus of this study is on SAE-level 4 Automated Vehicles, as safe interaction with cyclists is of more importance without a fallback-ready user. Additional information on the different levels of driving automation is included in Appendix A.

Additional context on SAE-level 4 Automated Vehicles relevant for this research is represented in Figures 1.2 and 1.3. SAE-level 4 Automated Vehicles can only operate within a specific Operational Design Domain (ODD). If the AV, referred to in Figure 1.2 as ADS (Automated Driving System), approaches the ODD exit, the passenger is prompted to take over the Dynamic Driving Task (DDT). If responding, the passenger becomes the driver and resumes the Dynamic Driving Task outside the ODD. If not responding, the AV achieves a minimal risk condition: *"A condition to which a user or an ADS may bring a vehicle after performing the DDT fallback in order to reduce the risk of a crash when a given trip cannot or should not be completed"* (SAE International, 2018, p. 11).

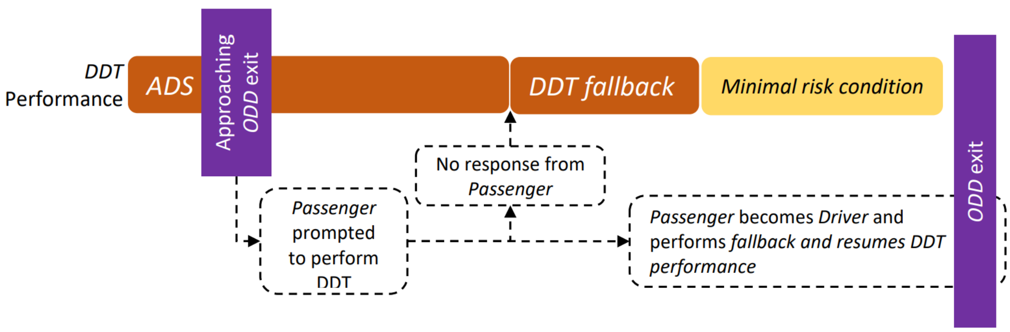


Figure 1.2: SAE-level 4 Automated Vehicle approaching Operational Design Domain exit (SAE International, 2018)

A similar situation where a minimal risk condition might be achieved is in case of an ADS failure (Figure 1.3). If an ADS failure occurs, thereby preventing continued DDT performance, a similar passenger request to take over is prompted. Again, if the passenger is not responding, the ADS brings the vehicle in a minimal risk condition.

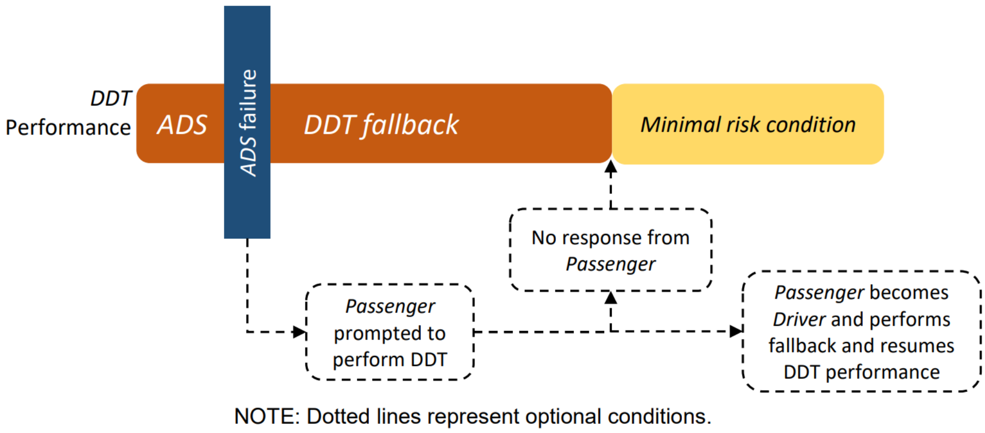


Figure 1.3: SAE-level 4 Automated Vehicle failure (SAE International, 2018)

Conservative behavior It is assumed AVs drive somewhat more conservative compared to Human Driven Vehicles (HDVs), to prevent accidents in the early stages of AV deployment (further discussion can be found in e.g. Hartmann et al. (2017); Schwarting et al. (2019)). It is furthermore assumed that AVs have difficulty with visual communication of cyclists, as detection of gestures is mentioned as one of the challenges of AVs (Mannion, 2019). If a situation is not understood correctly, the AV will behave in a conservative way to actively avoid accidents with cyclists.

1.3 Thesis Outline

This study is structured as follows. First, an overview of the research methodology and thereby the structure of this study is explained in Chapter 2. Then, a literature review is presented in Chapter 3, discussing the determinants affecting road safety between AVs and cyclists. Afterward, Chapter 4 goes more into detail about cyclist safety. An analysis of current bicycle-motor vehicle accidents is presented, along with Surrogate Measures of Safety that can be used to objectify road safety between AVs and cyclists. Chapter 5 subsequently presents the structure and results of the expert interviews that are held to identify conflict situations and their underlying accident risk factors. Based on the expert interviews, a methodology to assess road safety between AVs and cyclists is presented in Chapter 6. This methodology is then used to analyze the road infrastructure readiness in the province of Noord-Holland, and accident risk factors are presented. For Chapters 3 to 6, conclusions are presented at the end of each chapter, including the most important highlights. In Chapter 7, a discussion of the presented work is given, including an evaluation of the research methodology. Finally, Chapter 8 concludes by presenting the main results of this study and presenting recommendations for further research.

2 Research Methodology

This section describes the research methodology of this study, consisting of four different parts. First, a literature review is conducted focusing on road safety between Automated Vehicles (AVs) and cyclists. The literature review covers a broad overview of all determinants found to affect road safety. Determinants related to the road infrastructure, road user behavior, and AV characteristics are described. Based on the most important determinants, hypotheses on how to promote road safety are formulated.

The second part is to determine how to assess safety between AVs and cyclists. As SAE-level 4 AVs are not yet permitted on Dutch roads and thus do not drive around, it is difficult to determine the exact safety implications for cyclists. To give more background information on cyclist safety, safety numbers of current bicycle-motor vehicle (BMV) interactions are analyzed. This is done by diving into Dutch safety reports and analyzing all registered BMV accidents of the past ten years. Furthermore, currently used Surrogate Measures of Safety for cyclist safety are explored, and translated to a scenario with AVs. This resulted in a list of Surrogate Measures of Safety to assess road safety between AVs and cyclists. Based on these Surrogate Measures of Safety and current accident details, potential conflict situations are determined.

The third part of this study is interviewing experts. The determined conflict situations are presented to experts with different backgrounds: academic, governmental, and from the cyclist industry. The experts evaluated cyclist safety in each situation, with the presence of AVs. Cyclist safety is evaluated both quantitatively (by scores) and qualitatively (by arguments). The arguments given are categorized under the earlier defined Surrogate Measures of Safety. The results of the expert interviews present an overview of risk factors for each Surrogate Measure of Safety.

The fourth part analyzes the infrastructure readiness of the province of Noord-Holland. First, a classification of Surrogate Measures of Safety is made. Three different safety levels are distinguished for each Surrogate Measure of Safety, presented in a rubric. This classification is based on the results of the expert interviews, accident analysis, and literature review. Infrastructure readiness is analyzed for multiple provincial roads in Noord-Holland. All potential conflict situations for AVs and cyclists are listed. For each conflict situation, the rubric is used to determine the safety score for each Surrogate Measure of Safety, resulting in an overview of risk factors. Based on these results, methods to promote road safety are suggested. For these methods, a link with the hypotheses resulting from the literature review is made.

Before presenting the conclusions of the work, a discussion is provided. The discussion presents a reflection of the research methodology and results, and any further limitations are listed. Afterward, conclusions are given by answering each sub-research question. An overview of the research methodology is depicted in Figure 2.1. A more elaborate explanation of each part is provided in Sections 2.1 to 2.4.

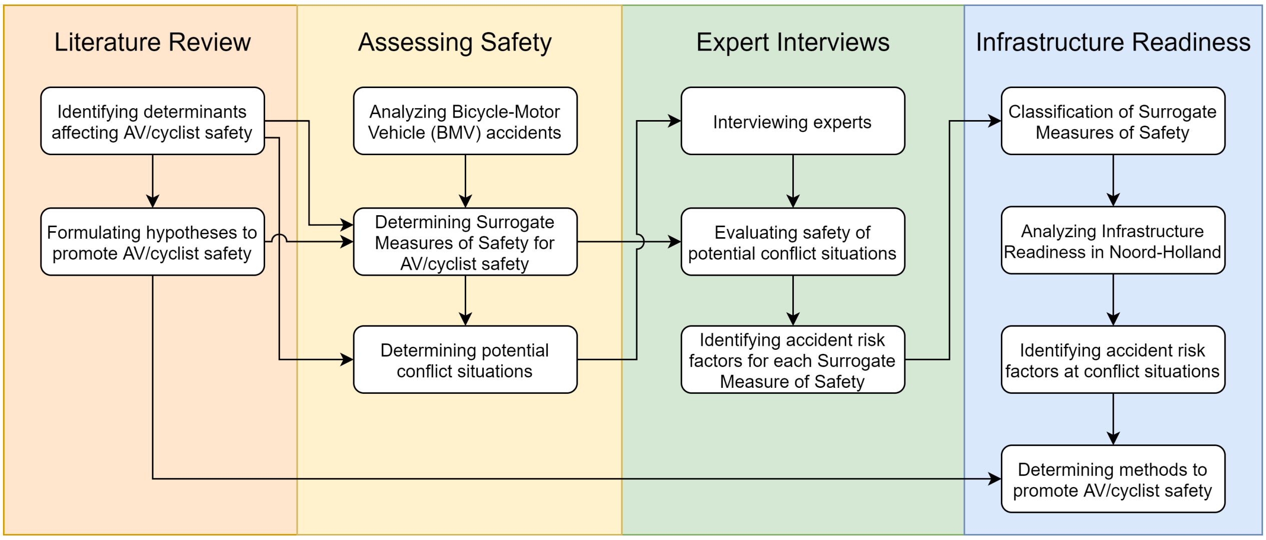


Figure 2.1: Overview of the research methodology

2.1 Literature Review

The first part of this study consists of an elaborate literature review, the main goal of which is to identify determinants affecting road safety between AVs and cyclists. First, the Situation Awareness theory of Endsley (1995) is presented, as this is an important basis for road safety and used throughout the literature review. The three levels of Situation Awareness are translated to a situation with AVs, and some challenges are presented.

Identifying determinants affecting AV/cyclist safety To identify determinants affecting road safety between AVs and cyclists, a conceptual framework from Schepers et al. (2017) is used as a basis. The framework, shown in Figure 2.2, consists of factors affecting the number of serious injuries and fatalities among cyclists. Literature used in the paper of Schepers et al. (2017) is studied to derive more information about the underlying determinants affecting road safety. When applicable to and interesting for the interaction between AVs and cyclists, the determinants are taken into account for this study. For each block in the conceptual framework (Figure 2.2), additional literature is searched for via Google Scholar and Scopus. This is done to add information about existing determinants, complement the list of determinants, and add more recent studies.

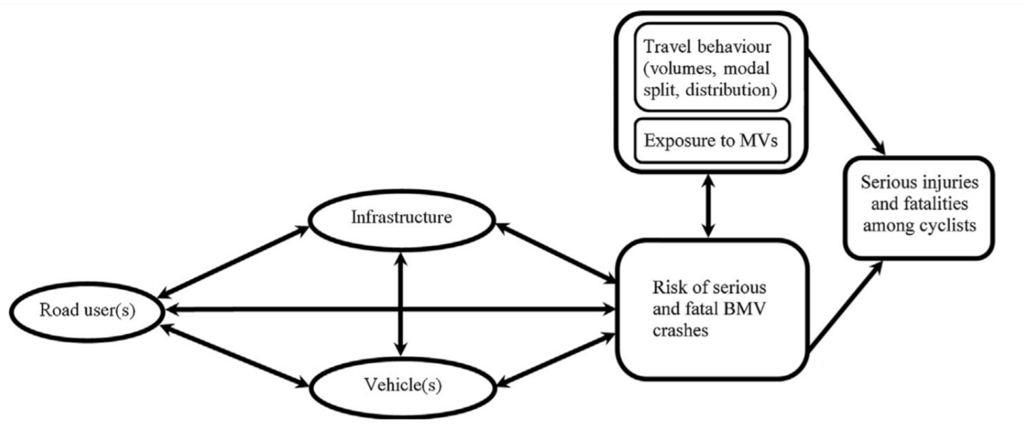


Figure 2.2: Conceptual framework on factors affecting road safety (Schepers et al., 2017), *(B)MV = (bicycle)-motor vehicle*

Formulating hypotheses to promote AV/cyclist safety After identifying the determinants, the conceptual framework of Schepers et al. (2017) is adjusted to a situation with Automated Vehicles instead of Motor Vehicles. The relationship between all categories is discussed, based on the identified determinants. An overview is presented of the determinants that are expected to have the most influence on road safety between AVs and cyclists. Based on the literature review and the resulting determinants, hypotheses for promoting road safety are formulated. In total, thirteen hypotheses are presented, from the perspective of cyclists, AVs, and road infrastructure. For each hypothesis, an explanation is given based on the findings of the literature review.

2.2 Assessing Safety

The goal of the second part of this study is to determine how road safety between AVs and cyclists could be assessed. As AVs are not yet permitted on Dutch roads, this is not straightforward. Furthermore, the majority of existing literature related to AVs is not focused on interaction with cyclists, as that is a typical Dutch situation.

Analyzing bicycle-motor vehicle (BMV) accidents First, current bicycle-motor vehicle (BMV) accidents are analyzed, to present additional background information on cyclist safety, especially when interacting with motor vehicles. This is done in two ways:

- *Looking at accident data from Dutch safety reports*
  Multiple Dutch safety reports have presented numbers on cyclist safety in the Netherlands. Relevant information on bicycle-motor vehicle (BMV) accidents is presented. However, the majority of reports are somewhat outdated,

and recent years are not taken into account. Although the numbers present a good overview of BMV accidents in general, some more specific information is desired. Furthermore, it is useful to take into account more recent years as well.

- *Analysis of recent Dutch accident databases*
  In the Netherlands, all traffic accidents documented by the police or road inspectors are included in a database called BRON (Bestand geRegistreerde Ongevallen in Nederland). This database is also used in many of the Dutch safety reports as discussed before, and the raw data is analyzed in more detail. Accident data of the past ten years is used (2010-2019), obtained via Nationaal Georegister (2020). A script in Python 3.7 is made to filter for fatal and serious BMV accidents only, reducing the raw dataset of N $\approx$ 1.1 million accidents to a total of N = 21.687 accidents. A descriptive analysis is conducted for these accidents, and visualizations are made with Microsoft Power BI.

Determining Surrogate Measures of Safety for AV/cyclist safety Although current BMV accident data presents an informative overview of cyclist accidents, it is not sufficient to determine safety. This is also advocated by Laureshyn et al. (2017, p. 11): *"Relying on accident records as the main data source for studying cyclists' safety has many drawbacks, such as high degree of under-reporting, the lack of accident details and particularly of information about the interaction processes that led to the accident. It is also an ethical problem as one has to wait for accidents to happen in order to make a statement about cyclists' (un-)safety"*. For assessing safety of AVs, these arguments are even more important and therefore Surrogate Measures of Safety are used to assess safety.

First, currently used Surrogate Measures of Safety for cyclist safety are searched for in literature and publications by Dutch organizations focusing on cyclist safety. For several publications, the most important Surrogate Measures of Safety are discussed. These Surrogate Measures of Safety are related to a situation with AVs, linking them to the formulated hypotheses if possible. Afterward, these Surrogate Measures of Safety are complemented with measures focused specifically on a situation with AVs. This resulted in a final list of eight Surrogate Measures of Safety that is taken into account for the remainder of this study.

Determining potential conflict situations Based on the accident details and identified Surrogate Measures of Safety, a list of potential conflict situations is composed. The list consists of different conflict types that are present outside city limits, or in close proximity to provincial roads. The expected positive and negative effects of AVs for each situation are presented, based on different characteristics of AVs and HDVs (Human Driven Vehicles). The potential conflict situations will be used as input for the expert interviews.

2.3 Expert Interviews

The main goal of the expert interviews is to gather a diverse range of information on possible risk factors affecting cyclist safety when interacting with AVs. In total, nine different types of the previously determined potential conflict situations were presented to the experts. In a semi-structured manner, the experts gave their opinion on how cyclist safety would be affected if AVs were to drive at those conflict situations.

Interviewing experts To collect a diversity of opinions, experts with different backgrounds are selected. The interviewed experts are from academic research parties, governmental bodies, or the cyclist industry. Most of the selected experts were chosen based on their experience with both cyclists and AVs. A total of fifteen experts were contacted via mail, of which eleven were willing to take part in an interview. Before conducting the interviews, two test interviews were held with experts from the TU Delft and the Provincie Noord-Holland, both experienced with cyclists and AVs. Based on these test interviews, some minor adjustments in the questioning were made, leading to the final structure as shown in Appendix B. The interviews are structured based on three goals:

- To determine the complexity of each potential conflict situation for AV/cyclist interaction
- To determine whether or not conflict situations would be included in the Operational Design Domain (ODD) of SAE-level 4 AVs
- To determine the safest and unsafest situations

The interviews were semi-structured: the same questions and situations were presented to all experts, but additional questions were asked if considered necessary. For each interview, a total of 45 minutes was planned. Ten interviews were conducted in October 2020, and one interview was conducted in November 2020. The interview duration ranged from 30 to 52 minutes, on average 43 minutes per expert. With the consent of the experts, all interviews were recorded for analyzing purposes only. The videos are used to create a transcript of each interview, which are then used to evaluate safety of the potential conflict situations and to identify risk factors.

Evaluating safety of potential conflict situations The data consists of both quantitative data (complexity scores and background questions) and qualitative data (reasoning for the complexity scores). The quantitative data is analyzed to compare the scores of each situation, and the safest and unsafest situations according to the experts are mentioned. The focus was on analyzing qualitative data, as much information is obtained via the interviews. For each situation, the reasons given by all experts were combined. For every situation specifically, the most interesting reasons leading to either safety or unsafety are presented and discussed.

Identifying accident risk factors for each Surrogate Measure of Safety Next to presenting the results per conflict situation, an overview of arguments related to each Surrogate Measure of Safety is given. As the scores and arguments for each situation are highly dependent on the specific visualization of the situation, it is not necessarily true that this is compatible with all types of this specific situation. For example, the priority intersection with through traffic is sometimes considered to be risky due to the reduced visibility caused by bushes. As this is of course not the case for each priority intersection, this does not mean that priority intersections are by definition unsafe. Therefore, the risk factors for each Surrogate Measure of Safety are identified, to be able to assess safety based on these risk factors instead of a single representation of a type of infrastructure.

If possible, each given argument was related to one of the predefined Surrogate Measures of Safety. As many experts gave reasons related to cyclist traffic violations, this was added as a separate Surrogate Measure of Safety. If a statement was not directly related to the Surrogate Measures of Safety, it was categorized as 'other'. An overview of all arguments, for each situation categorized per Surrogate Measure of Safety, is included in Appendix C.

2.4 Infrastructure Readiness Analysis

The fourth part of this study is to determine infrastructure readiness for a safe interaction between AVs and cyclists. First, a classification is made, distinguishing each Surrogate Measure of Safety in three different safety levels. Then, several provincial roads in Noord-Holland are analyzed to evaluate their scores for each Surrogate Measure of Safety. Problem locations and the underlying risk factors are identified, and methods to promote safety are suggested.

Classification of Surrogate Measures of Safety The expert interviews resulted in an overview of risk factors related to each Surrogate Measure of Safety. Based on these risk factors, combined with the conclusions of previous parts, a classification of Surrogate Measures of Safety is made. For each Surrogate Measure of Safety, a distinction is made in three different safety levels, derived from Wijlhuizen et al. (2014):

- *Adequate*: Safety level is sufficient for AV/cyclist interaction
- *Point of attention*: Safety level leads to minor risks for cyclist safety
- *Problem area*: Safety level leads to major risks for cyclist safety

This leads to a rubric, which can be used to assess the safety of conflict situations where AVs and cyclist are to interact. If needed, for each cell in the rubric some examples are illustrated, to provide additional clarity for the distinction in safety levels.

Analyzing infrastructure readiness in Noord-Holland The rubric with different safety levels for each Surrogate Measure of Safety is used to assess safety of potential conflict situations on provincial roads in the province of Noord-Holland. In total, 57 provincial roads in Noord-Holland are maintained by the Provincie Noord-Holland, totaling a length of 601 *km*. Of these roads, 14 are analyzed, with a total of 163.5 *km* (26.6%). Google Street View is used to virtually go over each road, identifying all potential conflict situations between AVs and cyclists. For each conflict situation, the Street

View data collection date was checked. If Street View data was considered to be outdated (i.e. before 2019), the situation was checked in Cyclomedia's Street Smart. As Cyclomedia updated their OpenStreetMap with 2020 data (Cyclomedia, 2020), it was verified if outdated situations were unaltered. If a situation was changed, the updated situation in Street Smart is used. Street Smart is furthermore used to determine the location of each conflict situation, based on the closest hectometer post. For each road, the potential conflict situations are listed. For each conflict situation, a score is given for all Surrogate Measures of Safety, based on the rubric. This results in an overview of infrastructure readiness for AV/cyclist interaction on the analyzed roads.

Identifying accident risk factors at conflict situations Based on the scores given at each conflict situation, accident risk factors are identified. conflict situations with major (*'problem area'*) and minor (*'point of attention'*) risks for cyclist safety are presented. Common accident risk factors for each Surrogate Measure of Safety are discussed, illustrated by figures representing actual conflict situations. An overview is given of frequent risk factors that cause conflict situations to be problematic.

Determining methods to promote AV/cyclist safety When the accident risk factors at conflict situations are identified, methods are suggested to promote safety at these locations. Methods will be presented from the perspective of both AVs and road infrastructure. A link will be made to the earlier formulated hypotheses, to determine which hypotheses are the most important to promote safety.

3 Literature Review

This chapter provides an overview of literature relevant for road safety between Automated Vehicles (AVs) and cyclists. An overview of the structure of this chapter is presented in Figure 3.1. First, Section 3.1 presents an overview of the Situation Awareness theory of Endsley (1995) that is used as a basis for this literature review. The Situation Awareness theory is translated to a situation with AVs and some challenges are presented. Second, determinants affecting road safety between AVs and cyclists are presented in Section 3.2. A conceptual framework of Schepers et al. (2017) for bicycle-motor vehicle interaction is presented to structure the findings. Determinants related to exposure, cyclists, drivers, AVs, and the road infrastructure are discussed. An overview of relevant literature for each determinant is presented and the implications for road safety between AVs and cyclists are discussed. Third, a synthesis of the findings is presented in Section 3.3, by highlighting the most important determinants. The conceptual framework of Schepers et al. (2017) is adjusted to comply with a situation where cyclists interact with AVs. Fourth, hypotheses to promote road safety are formulated in Section 3.4, based on previous findings. Finally, this chapter ends with a conclusion of the presented work.

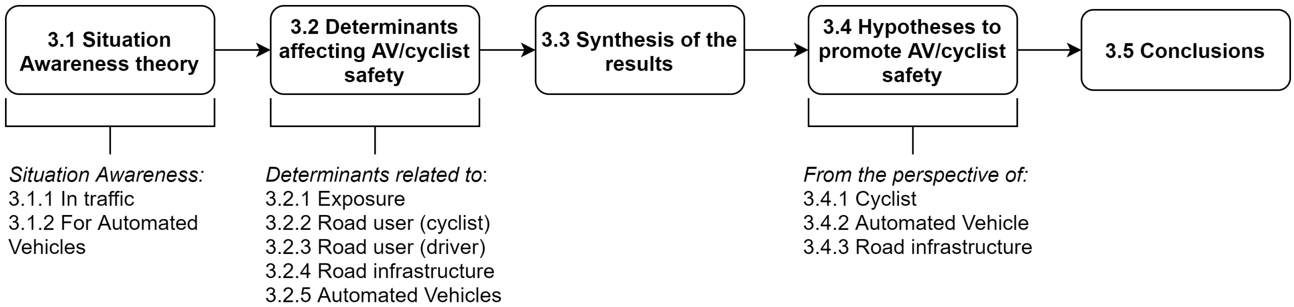


Figure 3.1: Overview of the structure of the literature review

3.1 Situation Awareness Theory

The Situation Awareness theory of Endsley (1995) is used as a basis for this literature review, to better structure the different aspects affecting road safety between AVs and cyclists. First, the three different levels of Situation Awareness (afterward referred to as SA) as defined by Endsley (1995) are presented. Afterward, the theory is used to describe Situation Awareness in traffic (Section 3.1.1) and specifically for Automated Vehicles (Section 3.1.2).

Endsley defines Situation Awareness as follows: *"Situation Awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future"* (Endsley, 1995, p. 36). Three levels of SA are distinguished, which will be used throughout this literature review:

1. Perception of the elements in the environment
2. Comprehension of the current situation
3. Projection of future status

For the first level, the status, attributes, and dynamics of all relevant elements are perceived. In traffic, one can think of among others traffic lights, road surface markings, road signs, own vehicle speed and position, and other road users' positions and their behavior as relevant elements (Salmon et al., 2012).

For the second level, a comprehension is made from all single elements of level 1. It goes a step further, as instead of only being aware of the present elements, an understanding of the significance of those elements is added (Endsley, 1995). For example, based on a traffic light turning yellow, a driver comprehends that the light will turn red shortly. If possible in time, a braking action needs to be performed. Significant elements to determine if this braking action can be performed in time are among others the vehicle speed and its position.

The third and final level is the projection of future status. Based on the status and dynamics of the elements (level 1) and comprehension of the current situation (level 2), the future status is projected (Endsley, 1995). Regarding the traffic sign example, it is projected if the vehicle can come to a complete stop before the traffic light, or not.

In dynamic decision making, of which traffic is a good example, the performance of actions is a result of a decision made based on all three levels of SA (Endsley, 1995). If the vehicle can stop in time, the driver brakes and subsequently the vehicle comes to a complete stop. Another factor influencing decision making is the goal or objective of the decision-maker. If doubting whether the vehicle can stop in time, the performance of actions can be influenced by this goal or objective. When in a hurry, a driver can decide to speed up to pass the light before it turns red.

Endsley's full model of Situation Awareness in dynamic decision-making is shown in Figure 3.2.

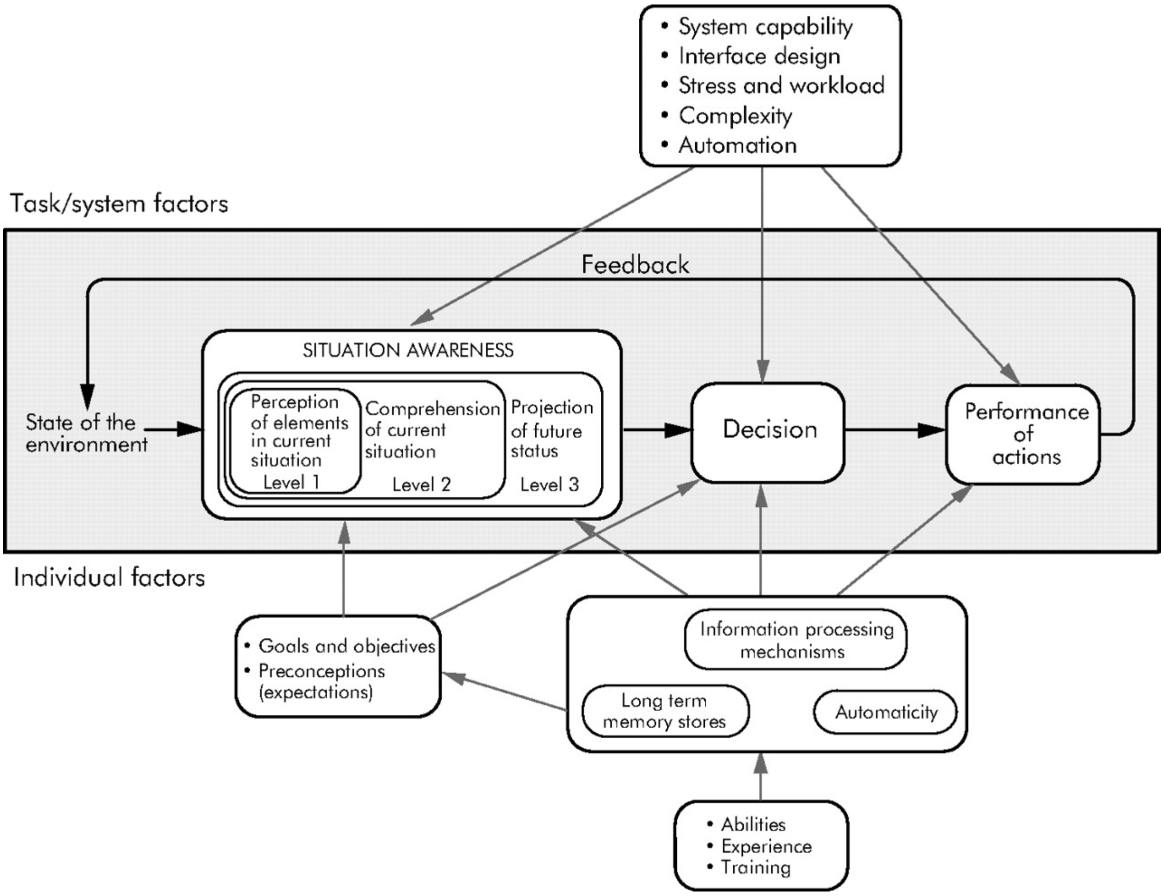


Figure 3.2: Model of Situation Awareness in dynamic decision making (Endsley, 1995)

3.1.1 Situation Awareness in Traffic

Traffic is an excellent example where dynamic-decision making is present, and Situation Awareness is thus important. Especially the interaction between multiple road users is important for the assessment of SA (Salmon et al., 2012). Different road users use different information for their SA in similar road situations (Salmon, Young, & Cornelissen, 2013). For example, Salmon, Lenné, et al. (2013) state that SA at intersections is different for drivers and cyclists, which can lead to conflicts. The efficiency and safety of the road transport system are determined by the compatibility of these differences in SA (Salmon et al., 2012).

For cyclists, head checks are an appropriate manner to increase Situation Awareness in traffic situations when interacting with vehicles. Frequent head checks lead to improved reactive behavior to driver actions, resulting in avoidance of collisions (Johnson et al., 2010). However, Johnson et al. (2010) also found that in general cyclists are less likely to check the side where no dangerous future situation is expected. The same behavior is observed for car drivers, as found by Summala et al. (1996, p. 147): *"it appears that drivers develop a visual scanning strategy which concentrates on detection of more frequent and major dangers but ignores and may even mask visual information on less frequent dangers"*.

In Endsleys' model of Situation Awareness (Figure 3.2), this is referred to as preconceptions (expectations). As the expectation of road users is that there is no danger coming from a specific side, a decision is often made without checking that side. This can for example be when a cyclist wants to make a left turn, where vehicles coming from the left need to give way to the cyclist. Cyclists may not value elements from the left as important before proceeding the intersection, as the expectation (and thus projected future status) is that any vehicle coming from the left will give way.

These expectations of absent danger can lead to conflicts, as other road users are not always acting according to the formal traffic rules. A study by Hunter et al. (2000) showed that expectations of absent danger decreased SA of cyclists. Although perceived safety increased, a side effect of using painted bicycle lanes was that fewer cyclists performed head checks to scan for traffic, or used hand signals to communicate their intentions.

3.1.2 Situation Awareness for Automated Vehicles

With the introduction of AVs and thereby the disappearing SA of human drivers, the interaction situation will change. Existing research on SA in combination with AVs focuses on the SA of the human driver in an AV (e.g. Endsley (2018); Miller et al. (2014); Son & Park (2017)). However, to the best knowledge of the author, no research was found on the SA of AVs and other road users, when interacting with each other. It is apparent that, using e.g. cameras and sensors, AVs interpret traffic situations in a different manner than humans. As the compatibility of the SA of different road users is important (Salmon et al., 2012), the question is whether the introduction of AVs decreases this compatibility. If the compatibility is reduced, and situations are not interpreted correctly (both by a cyclist or an AV), this can lead to dangerous situations and eventually to (fatal) accidents.

The three levels of Situation Awareness as identified by Endsley (1995) can be translated to AVs, albeit with different terms. The three levels to create SA for AVs can be specified as follows:

1. Object detection (to perceive the elements)
2. Object classification (to comprehend the situation)
3. Object trajectory prediction (to project future status)

The change from human car drivers to automated driving will lead to challenges for SA on all three levels.

For the first level, the challenge for AVs is to detect all objects and thus perceive all important elements in the environment. False positives (i.e. falsely detecting an object) and false negatives (i.e. failing to detect an object) need to be minimized, as both can lead to dangerous traffic situations. False positives can lead to unnecessary braking of the AV which is not expected by succeeding vehicles. Schwarting et al. (2019) found that in the majority of accidents involving AVs in California, the AV is rear-ended by human drivers. False negatives have also shown to lead to accidents: e.g. a Tesla in autopilot mode (SAE-level 2) not perceiving a fire truck or a truck-tractor semitrailer in time (NTSB (2019b), NTSB (2020) respectively). Whereas nobody was injured in the first accident, the latter resulted in the fatality of the Tesla driver.

For the second level, the AV must be able to identify and comprehend all relevant elements. For proper SA, it is important that all important elements are recognized, while all unimportant elements are ignored. When the current situation is incorrectly comprehended, this can lead to fatal accidents. An example is an accident in Arizona in 2018, involving an Uber test vehicle and a pedestrian who was pushing a bicycle by her side. According to the NTSB (2018), the automated driving system detected the pedestrian several seconds before the impact. However, it never classified the pedestrian as being a pedestrian, nor did it predict its path. In the preliminary report it is stated that the automated driving system first classified the pedestrian as an unknown object, then as a vehicle, and finally as a bicycle (NTSB, 2018). The accident resulted in the fatality of the pedestrian.

For the third level, the AV needs to adequately predict the future trajectory of the other road user. When the automated driving system cannot comprehend the situation correctly, it is difficult to project the future status and act accordingly. Furthermore, even if the situation is comprehended accurately, it is still hard to predict the intention of a cyclist solely based on visual cues (Westerhuis & de Waard, 2017). In addition, as there are different types of cyclists (see e.g. Dill & McNeil (2013) or Cannegieter et al. (2019)), another question is to what extent these different types show different behavior, leading to diverse possibilities of their future status. It is interesting to know whether AVs need to be able to take into account different possible future statuses, or if it is sufficiently safe if they project a single intention for all cyclist types in similar situations. Although not exclusively present for AVs, another aspect that makes a correct projection of the future status more difficult is unsafe behavior of vulnerable road users. This was also found to be one of the causes of the Uber accident in Arizona, as the pedestrian's crossing behavior was unsafe and against the law, possibly even influenced by drug use (NTSB, 2019a). Unsafe and violating behavior of vulnerable road users is not primarily expected by automated driving systems, presumably leading to an incorrect projection of future status.

On the other hand, the introduction of AVs might lead to incorrect SA of other road users such as cyclists. This holds in particular for the projection of future status (level 3), as the driving behavior of AVs and HDVs (Human Driven Vehicles) can differ (Vlakveld et al., 2020). Cyclists might have difficulty with predicting the intentions of an AV. One of the reasons is that cyclists are not per definition confident of the skills of AVs (Vissers et al., 2016). Hagenzieker et al. (2020) showed in a photo-experiment that cyclists tended to be more cautious towards AVs compared to HDVs, as they did not expect to be noted better by an AV. This indicates cyclists have difficulties with projecting the future status of AVs, e.g. if the AV will give way or not, leading to more cautious behavior. This is also researched by Vlakveld et al. (2020), showing that cyclists who had priority yielded more often for an AV who did not display its intentions, compared to an AV who was able to communicate its intentions to the cyclist. Vlakveld et al. (2020) concluded that displaying AV intentions may help cyclists to make the right projection of future status. Next to communicating its intentions (especially next maneuvers), knowledge about vehicle automation status, perception of the environment, and cooperation capabilities enlarge other road users' SA when interacting with AVs (Schieben et al., 2019).

3.2 Determinants Affecting Road Safety Between Automated Vehicles and Cyclists

To identify determinants affecting road safety between AVs and cyclists, a conceptual framework from Schepers et al. (2017) is used as a basis. In their paper, the authors explored which factors were found to contribute to the high level of cycling safety in the Netherlands, focusing on bicycle-motor vehicle (BMV) accidents. The framework, shown in Figure 3.3, consists of factors affecting the number of serious injuries and fatalities among cyclists. The first factor is travel behavior and exposure to motor vehicles (MVs). The volumes, modal split, and distribution of traffic over space determine the number of motor vehicles encountered by cyclists, and thereby their exposure to risk (Schepers et al., 2017). Another factor is the risk of serious and fatal BMV accidents, which results from the interaction between road user(s), vehicle(s), and infrastructure. These three elements are derived from Othman et al. (2009), who mentioned these as major traffic safety pillars.

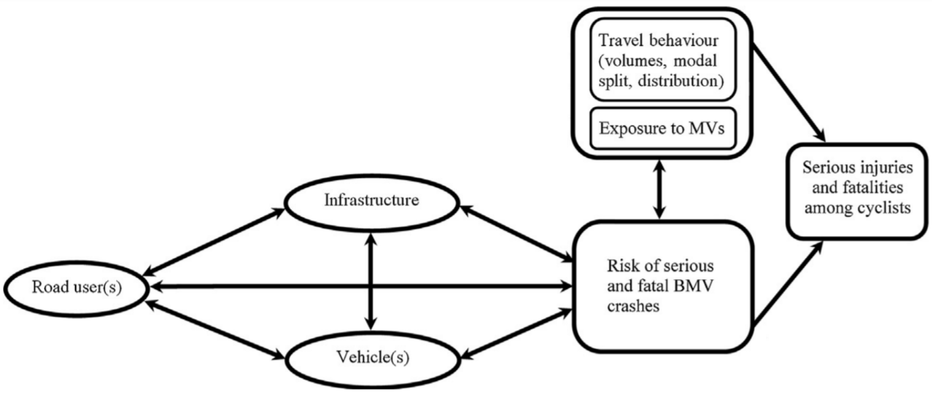


Figure 3.3: Conceptual framework on factors affecting road safety (Schepers et al., 2017), *(B)MV = (bicycle)-motor vehicle*

Some adaptations to the structure of the conceptual framework are made to comply with the interaction scenario of AVs and cyclists. Travel behavior and exposure to motor vehicles is changed to exposure to Automated Vehicles. Furthermore, whereas Schepers et al. (2017) integrate factors for both car drivers and cyclists under road user(s) in their storyline, this is separated in this study to create a clearer segregation. Although car drivers are not in control of an AV (from SAE-level 4 onwards) and thus not primarily relevant for this study, their current driving behavior shows interesting factors that could be taken into account for the interaction between AVs and cyclists. Additionally, cyclist behavior is affected by interaction with car drivers. When a cyclist does not recognize an AV, it will behave like the AV is a conventional vehicle. Literature focusing on AVs, especially when interacting with cyclists, is searched for to complement for determinants relating to AVs.

For each factor in the framework of Schepers et al. (2017) (Figure 3.3), the determinants that are found to affect road safety between AVs and cyclists are discussed in Sections 3.2.1 to 3.2.5. Afterward, a synthesis of the findings for each factor is presented in Section 3.3, by highlighting the most important determinants.

3.2.1 Determinants Related to Exposure

Exposure to AVs is an important factor affecting road safety of cyclists. If exposure is low, the probability of accidents is also low. On the other hand, a large exposure is related to an increased probability of accidents. To fully eliminate exposure, cyclists should be separated from AVs at all times. In the current road infrastructure network in the Netherlands, that is not possible. Therefore, exposure between AVs and cyclists remains. Figure 3.4 gives an overview of the determinants found to affect this exposure. The determinants are divided into two categories: cyclist volumes and distribution over the network.

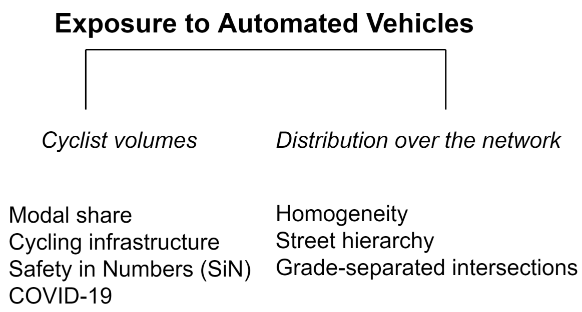


Figure 3.4: Determinants related to the exposure to Automated Vehicles

Cyclist volumes An increase in cyclist volumes leads to more exposure, as more cyclists can be encountered by AVs. Most recent numbers show that the number of yearly cyclist trips in the Netherlands is 4.8 billion (de Haas & Hamersma, 2020). de Haas & Hamersma (2020) state cyclist volume is largest in morning peak hour and in (highly) urbanized areas. Determinants related to cyclist volume that will be discussed are the modal share, cycling infrastructure, Safety in Numbers, and the influence of COVID-19.

Modal share
In 2019, the modal share of cyclists in the Netherlands was 28% (de Haas & Hamersma, 2020). For distances of 0.5 to 3.5 *km*, the modal share of cyclists was even more than 40%. When looking at BMV interaction, a higher modal share reduces the exposure of cyclists to motor vehicles, thereby increasing safety (Schepers et al., 2017). Schepers & Heinen (2013) found that an increase in modal share of 7% would reduce the number of fatalities per billion bicycle kilometers by 10%. This is among others caused by a decrease in modal share of vehicles. For the interaction between AVs and cyclists, this is not the case, as there is currently no modal share of AVs. An increase in modal share will lead to an increase in cyclist volume, thereby enlarging exposure. In a future where AVs are widely available, modal share of cyclists might be reduced, as cyclists can switch to using AVs (Snelder et al., 2019).

Cycling infrastructure
A high-quality cycling infrastructure is one of the reasons for the large cycling volumes in the Netherlands (Schepers et al., 2017). This is also advocated in the Dutch Design Manual for Bicycle Traffic (CROW, 2016), stating proper cycling infrastructure leads to a higher share of cyclists. This is e.g. found by Félix et al. (2020) and Hong et al. (2020), showing an increase in cyclist volumes after an expansion of the cycling network.

Safety in Numbers
An increase in cyclist volumes is related to an increase in cyclist safety. This phenomenon, called Safety in Numbers (SiN), is introduced by Jacobsen (2003), stating that an increase in pedestrians and cyclists leads to safer walking and

cycling. This phenomenon is adopted by CROW (2016), advising to increase cycling volumes at intersections to improve safety. The effect of Safety in Numbers is among others shown by Buehler & Pucher (2020), concluding that walking and cycling levels correlate strongly with safety levels. The effect is presumably caused by an increased attention of motorists towards pedestrians and cyclists (Jacobsen, 2003). Contrary to human drivers, AVs are continuously monitoring their environment in 360 degrees. Therefore, the effect of the SiN phenomenon is expected to be smaller for AVs.

COVID-19
Cyclist traffic volume is furthermore influenced by the COVID-19 pandemic situation. Although the number of trips remained fairly constant, the average distance cycled has increased in the Netherlands during the first months of the pandemic de Haas & Hamersma (2020). 20% expects to walk and cycle more when the situation is back to normal (de Haas et al., 2020). The change in cyclist traffic volume was found to result in an increase in cyclist accidents (Donkers & Broos, 2020). It is uncertain how the pandemic affects mobility in the future, but it can be expected that the attitude towards cycling is strengthened.

Distribution over the network Another aspect found by Schepers et al. (2017) to influence exposure in case of BMV interaction, is the distribution of traffic over the road network. Three determinants mentioned by Schepers et al. (2017) are discussed: homogeneity, street hierarchy, and grade-separated intersections.

Homogeneity
Homogeneity is one of the road safety principles used in the previous Sustainable Safety editions (SWOV, 2018). According to Schepers et al. (2017, p. 267), homogeneity *"implies that differences in speed, direction and mass should not be too large"*. For the interaction with cyclists and motor vehicles, SWOV (2018) suggests that there are no conflicts at vehicle speeds exceeding 30 km/h. If the speed is larger at a possible conflict, it should be reduced or cyclists should be segregated. Regarding the interaction with cyclists and AVs, a desired maximum speed limit for conflict situations with cyclists is yet to be determined.

Street hierarchy
Another determinant related to distribution over the network is street hierarchy. Based on the homogeneity principle, the location of cyclists is different for different street hierarchies. Schepers et al. (2017) mention three different street types: access roads, distributor roads, and through roads. Access roads provide access to origins and destinations. The speed limit is often 30 km/h, and cyclists are mixed with other traffic. Distributor roads, distributing traffic from through roads to access roads, mostly have a speed limit of 50 or 70 km/h. Cyclists are separated from motor vehicles either by bicycle paths or bicycle lanes, the difference of which is explained in Section 3.9. Through roads are designed for large traffic flows. The speed limit is 100, 120, or 130 km/h, and cycling is not allowed. Schepers et al. (2017) conclude that this street hierarchy *"strongly reduces cyclists' exposure to motorised traffic by shifting vehicles away from where there is a lot of cycling"*. As interacting with cyclists is challenging for AVs, it can be expected that AVs first are permitted where few or no cyclists are encountered based on street hierarchies.

Grade-separated intersections
From a cyclist safety perspective, grade-separated intersections are ideal when crossing motor vehicle flows. By physically segregating cyclists from motor vehicle flow at distributor roads, e.g. by bicycle bridges or tunnels, cyclist safety is strongly improved (Schepers et al., 2017). Physical separation at road sections is also found to reduce the risk of BMV accidents (Thomas & DeRobertis, 2013). For AVs, there is no exposure to cyclists if always physically or grade-separated from cyclists, both at road sections and intersections. However, that is not realistic, as that requires many changes to the existing road infrastructure.

3.2.2 Determinants Related to the Road User (cyclist)

Determinants related to cyclists are an essential aspect of the interaction between AVs and cyclists. Therefore, the determinants and their relation to safety are discussed in more detail. A visualization of the determinants related to cyclists is provided in Figure 3.5. Per category, all determinants and relevant literature will be discussed.

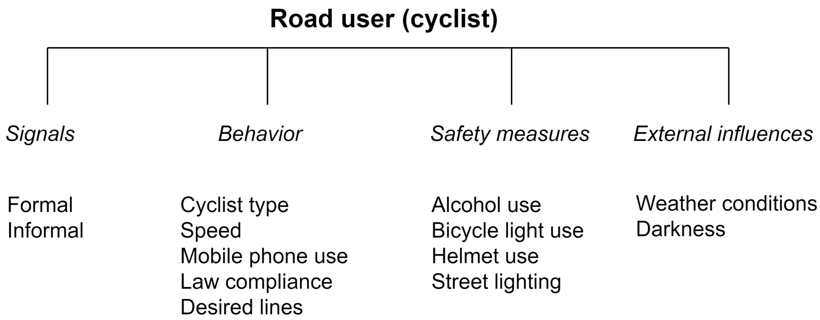


Figure 3.5: Determinants related to the road user (cyclist)

Signals The first category is signals, consisting of formal and informal signals.

Formal signals
Cyclists are supposed to communicate their intentions by using arm signals, which works well to inform drivers (Walker, 2005), and thereby increasing their SA. Although these arm signals are easy to perceive for drivers and are obligated in the Netherlands [1], not every cyclist uses arm signals. During morning rush hour in Amsterdam, the Netherlands, only 4% of cyclists was found to indicate their direction by using arm signals (Bol et al., 2016). Without clear arm signals, it will be more difficult for AVs to correctly predict the future status of cyclists.

Informal signals
Informal signs of intention can also be used for SA level 1. Westerhuis & de Waard (2017) mention seeking eye contact, trailing a foot, and maintaining a certain position on the road as possible informal signs. The authors concluded that cyclists going straight have a higher speed and seem to be positioned slightly more to the right, compared to cyclists making a turn. Furthermore, cyclists turning left showed head movements more frequently to increase their SA. However, in general, it turned out to be very hard to predict a cyclists' intention solely based on informal signals (Westerhuis & de Waard, 2017). Other informal signals used for predicting a cyclists' intention are speed change (slowing down, accelerating, or no change), position on the bike (leaning or sitting straight), and pedaling (stopping or continuing) (Hemeren et al., 2014). All informal signals mentioned could be used by AVs to predict possible turning intentions of cyclists.

Behavior The second category is related to cyclist behavior. The determinants that will be discussed are cyclist type, speed, mobile phone use, law compliance, and desire lines.

Cyclist type
While interacting with cyclists, identifying and understanding their behavior is important for all three levels of SA. However, cyclist behavior is not similar for all cyclists, leading to a classification of cyclist types to better understand this non-homogeneous behavior (Dill & McNeil, 2013). Dill & McNeil (2013) show multiple examples of literature categorizing cyclist types, many of which are based on cycling frequency and risk-taking behavior. The latter is also used by Fyhri et al. (2012), who concluded that *'speed happy'* cyclists seem to be more frequently involved in cycling accidents. AVs might have difficulty projecting the future status of a cyclist if there are multiple possible future scenarios caused by differences in cyclist type. A classification of cyclist types specifically for the Netherlands is provided in Cannegieter et al. (2019).

A specific type of cyclist that shows more risk-taking behavior is cyclists on e-bikes. Bai et al. (2013) found that in particular red-light running is more frequently observed for cyclists on e-bikes, which is supported by Pai & Jou (2014). Additionally, Ma et al. (2019) found that this risk-taking behavior causes more than 90% of e-bike traffic accidents. Interesting to mention for red-light running behavior is that the majority of red-light running (both e-bikes and conventional cyclists) takes place in the early and late stages of a red-light cycle (Wu et al., 2012).

[1] *Although not enforced* (`https://nos.nl/artikel/2269957-fietser-kan-talloze-boetes-krijgen-maar-controle-is-er-vooral-op-licht.html`), *not using arm signals can result in a €35,- fine:* `https://www.fietsersbond.nl/ons-werk/wetten-en-regels/boetes-voor-fietsers/`

Speed
Closely related to cyclist type, is cyclist speed. Summala et al. (1996) showed that a lower cyclist speed (as well as lower vehicle speed) provides drivers more time for scanning the environment, positively influencing their SA. Furthermore, Schepers et al. (2014) suggested that cyclist speed is directly related to injury severity. Next to cyclist speed, vehicle speed also affects injury severity: Kim et al. (2007) showed that higher vehicle speeds prior to impact result in an increased probability of a cyclist fatality.

Mobile phone use
Since mobile phones are widely used, using a phone while cycling is quite common in the Netherlands (Goldenbeld et al., 2012). Whereas in 2008 the majority was calling (de Waard et al., 2010), in 2015 most cyclists were texting (de Waard et al., 2015). Mobile phone use negatively affects road safety, as it leads to more dangerous behavior (Terzano, 2013). This is because using a mobile phone while cycling leads to a diminished peripheral view, and probably also to reduced SA (de Waard et al., 2010). The decrease in peripheral view is largest when texting on a touchscreen smartphone, as fixations on a small screen are required (de Waard et al., 2014). De Waard furthermore said in a podcast that there are many situations where using a mobile phone while cycling is not per definition more dangerous, but it is if a vehicle is nearby (de Waard, 2019). For the interaction between cyclists and AVs, this means that mobile phone use while cycling increases the chance of conflicts because SA of the cyclist is reduced. Although a new law was introduced in the Netherlands in 2019 that prohibits phone use while cycling[2], four out of five young people still use their phone.[3] This suggests that this dangerous cyclist behavior will remain a problem when AVs are introduced.

Law compliance
Law compliance of cyclists is another determinant that can lead to dangerous situations. There are multiple possible situations where cyclists violate the formal rules in the law. Examples are cycling on the sidewalk, cycling in the wrong direction, cycling without a proper working bicycle, and red-light running. Although all these behaviors are against the law in the Netherlands, it happens frequently. For example, over 25% of cyclists in The Hague, the Netherlands, was reported to run the red light (van der Meel, 2013). van der Meel (2013) found that men and young people violated the red light more often, which is also found by Wu et al. (2012). Although high percentages of violating behavior were reported in both studies, no accidents happened. This suggests that in the majority of situations, violating cyclist behavior is executed in a rather safe way. One of the expected reasons for the low accident rate is that cyclists communicate with vehicles to display their intentions, among others with arm signals and by making eye-contact (Walker, 2005). Furthermore, cyclists especially pay attention to approaching vehicles that are potentially hazardous and direct less attention to the vehicle when it stopped or passed an intersection (Kovácsová et al., 2018). Based on this communication and focus of attention, a cyclist can estimate whether it is sufficiently safe to violate the law in each specific situation and behave accordingly. An important question is whether these traffic violations can still happen in a rather safe way when cyclists are interacting with AVs.

Closely related to this compliance to formal rules, is informal cyclist behavior based on informal rules. With informal cyclist behavior, the following situations are meant:

- Situations where cyclists do not have right of way, but they take or get it
- Situations where cyclist have right of way, but they do not take or get it

This informal behavior can arise in multiple situations and is important to take into account for AVs, as the projection of future behavior (SA level 3) is not only based on formal traffic rules, but also on informal traffic rules (Bjorklund, 2005). An example of informal cyclist behavior is observed at zebra crossings, as studied by Bjørnskau (2017). Formally, cyclists do not have right of way at these crossings, as they are intended for pedestrians. However, at multiple zebra crossings studied, the majority of drivers yielded to cyclists. Although not based on formal rules, it might give cyclists the impression that they have right of way at a zebra crossing. Situations where informal behavior can occur are problematic, as serious conflicts can arise if one road user follows a formal rule, whereas another follows an informal rule (Bjorklund, 2005). For AVs, it will be challenging to determine if a cyclist intends to behave in a formal or an informal way, and act accordingly. It is expected that this will lead to conflicts if AVs do not take informal cyclist behavior into account. Other

[2] https://zoek.officielebekendmakingen.nl/stb-2019-237.html
[3] https://www.hartvannederland.nl/top-nieuws/2019/smartphoneverbod-op-de-fiets-heeft-weinig-effect-veel-jongeren-doen-het-nog-steeds/

examples of informal cyclist behavior are e.g. cyclists taking right of way during rainy conditions, or cyclists giving right of way to a vehicle to improve traffic flow.

Desire lines

Another type of cyclist behavior that can lead to hazardous situations are cyclist paths that deviate from the designed paths: also called desire lines. Cyclists do not always follow the path they are supposed to follow based on the infrastructure. All different paths cyclists take, e.g. at intersections, can be visualized as done by te Brömmelstroet (2014). The lines in Figure 3.6 represent actual cyclist behavior at an intersection in Amsterdam, the Netherlands. It can be seen that many different paths are used by cyclists, which can lead to conflicts when interacting with AVs. If AVs always expect a cyclist to use the path that is supposed to follow, the projection of the future status of the bicycle (SA level 3) can be incorrect.

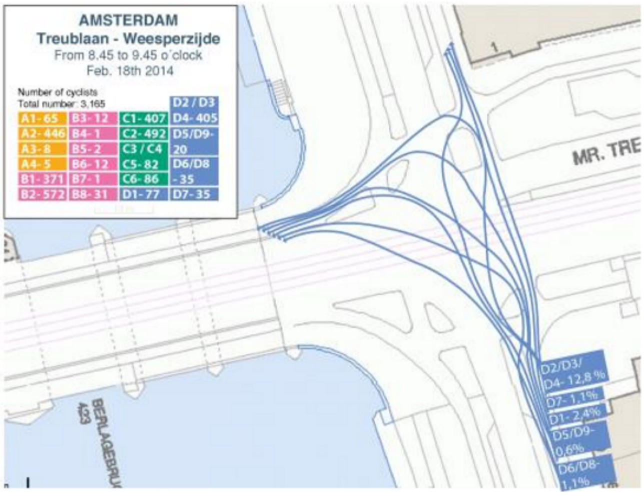


Figure 3.6: Example of cyclist Desire Lines (te Brömmelstroet, 2014)

To show the effect of these desire lines on traffic safety, te Brömmelstroet (2014) distinguished three categories of behavior:

- *Conformists:* cyclists who follow the formal rules and designed paths;
- *Momentumists:* cyclists who deviate from the formal rules and designed paths, without creating a dangerous situation or conflict;
- *Recklists:* cyclists who ignore formal rules and designed paths, thereby creating a dangerous situation or conflict.

The results show that the majority of cyclists are conformists (87%), but the number of momentumists (7%) and recklists (6%) is substantial (te Brömmelstroet, 2014). Most crossings have desire lines around traffic isles[4], in the middle of the intersection, on sidewalks, and in the wrong cycling direction. Whereas human drivers may expect this behavior, possibly based on their own experience as a cyclist, AVs might have difficulties with projecting bicycle trajectories that are not based on infrastructure.

Safety measures Another category related to cyclists and their risk of serious and fatal BMV accidents, is safety measures. Safety measures is an umbrella term used for multiple measures that lead to the prevention of accidents or mitigation of injury severity of an accident. The determinants discussed are alcohol use, bicycle light use, helmet use, and street lighting.

Alcohol use

One of the measures to increase safety is reducing alcohol use in traffic. Alcohol use, both for drivers and cyclists, leads to an increased likelihood of BMV accidents (Schepers et al., 2017). Next to that, alcohol use increases the chance of injuries and deaths in these accidents (e.g. Hingson & Winter (2003); Ogden & Moskowitz (2004)). With AVs from SAE-level 4 onwards, meaning no driver take-over is required in the Operational Design Domain (ODD), driver alcohol use is

[4] *'Vluchtheuvels' in Dutch*

no problem anymore. However, cyclist alcohol use is still a problem, as their driving performance decreases (Hartung et al., 2015), leading to less predictable behavior and thus an increased difficulty to correctly predict their future intentions. Whereas human drivers are creative and inventive when encountering such unfamiliar problems (SWOV, 2018), for AVs it is more difficult to adjust to unexpected events (Endsley, 2018). Therefore, AVs are expected to have more difficulty when interacting with cyclists under influence.

Despite the negative consequences of cycling under influence, it is quite common to do in the Netherlands. de Waard et al. (2016) showed that on a night out, 62% of cyclists had a Blood Alcohol Concentration (BAC) above zero, and 42% of cyclists had a BAC above the legal limit of 0.5g/l. During night hours, these shares increase to 90% and 80% respectively. Although it is illegal, cycling under the influence is rarely enforced: in 2018, only 20 cyclists in Amsterdam received a fine (Spaans, 2019). It is not expected that this behavior will change, as it looks like it is socially accepted (Reurings, 2010). For the interaction between AVs and cyclists, this means that cyclist alcohol use can be detrimental to road safety. Unexpected actions of cyclists can be misinterpreted by AVs, leading to dangerous situations.

Bicycle light use
Another safety measure is increasing bicycle light use. The use of bicycle lights is actively being promoted and enforced in the Netherlands (Schepers et al., 2019). However, still many cyclists do not wear lights: in 2019/2020, only 74% of observed cyclists used both front and rear lights (Bijlsma-Boxum & Broeks, 2020). Not wearing lights is in particular observed for young people. In 2019, this led to more than 50.000 fines in the Netherlands (SWOV, 2020). Not wearing lights is related to accident risk: Kuiken & Stoop (2012) found that the risk of injury decreases by approximately 17% when wearing lights. Interesting to mention is that a small amount of cyclists wears light on their body or head. Although it is observed for less than 1% of cyclists (Bijlsma-Boxum & Broeks, 2020) it is important to take into account. If AVs are not familiar with this behavior, they might have difficulty classifying these cyclists as being cyclists.

Helmet use
Helmet use does not prevent bicycle accidents, but is intended to decrease injury severity of cyclists involved in accidents (Vlakveld et al., 2019). Although more effective in single bicycle accidents, helmet use is proven to reduce serious and fatal head injuries in BMV accidents (Høye, 2018). Although bicycle helmet use is not mandatory in the Netherlands, it is in many other countries (Esmaeilikia et al., 2018). In the Netherlands, helmets are occasionally used by cyclists. Recent counts showed that only 0.7% of cyclists in the Netherlands wear a helmet: 0.4% of conventional cyclists, and 1.7% of cyclists on e-bikes (Bijlsma-Boxum & Broeks, 2020). Whereas many studies have the hypothesis that helmet use leads to more risk-taking behavior, Esmaeilikia et al. (2019) reviewed twenty-three studies, concluding that there is little to no supportive evidence of this hypothesis. Many of the reviewed studies even showed that wearing a helmet was associated with safer cycling behavior.

Street lighting
Street lighting is another safety measure, leading to increased visibility of cyclists. Multiple studies found that the presence of street lighting is associated with a decreased injury severity of cyclists in BMV accidents (e.g. Kim et al. (2007); Boufous et al. (2012); Chen & Shen (2016)). On the other hand, street lighting might reduce the performance of AVs. Streetlights decrease the functionality of the Lane Keeping System and Lane Departure Warning, because the detection performance of lines is lower (Reddy et al., 2020). In rainy conditions, this effect is found to be stronger. This leads to a paradox for safety, as street lighting improves cyclist visibility, but decreases AV performance.

External influences The last category related to cyclist behavior is external influences. These external influences affect the risk of serious and fatal BMV accidents, by causing poor visibility of cyclists. This poor visibility, which can lead to conflicts, is mainly caused by adverse weather conditions or darkness. These external influences are currently determinants leading to decreased cyclist safety, and this can pose even larger problems in the future if AVs have difficulty with detecting cyclists in these situations. On the other hand, if the technology in AVs is better in cyclist detection in these adverse conditions than humans, cyclist safety is positively influenced. By all means, it is important to know to what extent AVs are able to detect cyclists in darkness and different weather conditions, before AVs are permitted on roads where cyclists can be encountered.

Weather conditions
Adverse weather conditions, such as rain, fog, or snow, are indicated by drivers to be one of the most problematic occasions

for the interaction with cyclists (Basford et al., 2002). When looking at the effects on cyclist safety, Billot-Grasset et al. (2016) showed that bad weather plays a role in 13% of cycling accidents in France.

Darkness
Darkness is another external influence that is detrimental to cyclist safety. Whereas only 10% of cycling distance in the Netherlands is traveled during darkness, 14-17% of seriously injured cyclists in BMV accidents took place in the dark (Reurings, 2010). The study by Billot-Grasset et al. (2016) showed similar results, where 14% of cycling accidents happened during darkness. Next to poor visibility in the dark, fatigue of cyclists might also contribute to higher injury risk in the hours that it is dark, as that would be the period that a cyclist is usually asleep (Twisk & Reurings, 2013).

3.2.3 Determinants Related to the Road User (driver)

Next to cyclist behavior, driver behavior also affects the number of serious and fatal injuries among cyclists in BMV accidents. Although drivers do not have a critical function in AVs from SAE-level 4 onwards, it is interesting to observe their current behavior when interacting with cyclists. Safe behavior towards cyclists can be used as input for AV programming, whereas unsafe behavior must be excluded as much as possible. Additionally, for the behavior of AVs to be correctly predicted by cyclists, it must be similar to that of current drivers. If AVs behave contrasting to HDVs, this can result in a wrong projection of their future status by cyclists (SA level 3), possibly leading to conflicts.

Three determinants related to drivers are worthwhile to mention, as shown in 3.7. Relevant literature related to driver experience, cycling experience, and infrastructure familiarity is discussed.

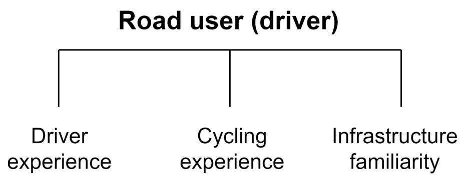


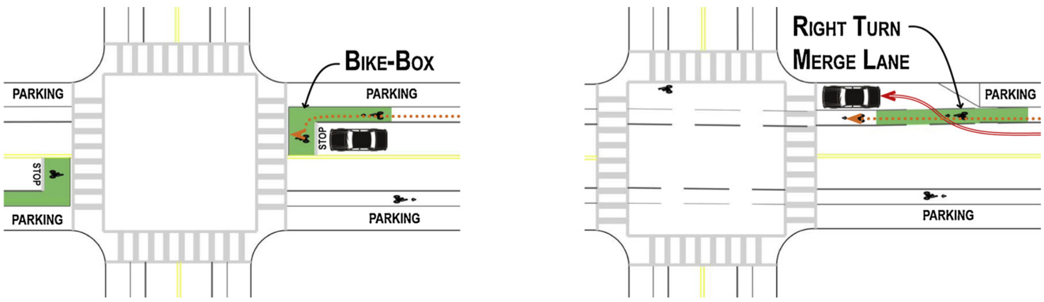
Figure 3.7: Determinants related to the road user (driver)

Driver experience
For driver experience, two interesting effects are observed. On the one hand, the accident risk of novice drivers (18-24 years old) is higher than that of older drivers (30-59 years old) (SWOV, 2016). According to SWOV (2016), this is due to factors relating to lack of experience (incorrect hazard perception and risk assessment) and sensitivity to the social environment (alcohol, drugs, and distraction). On the other hand, more driver experience can also lead to dangerous situations, as expressed by Herslund & Jørgensen (2003). First, experienced drivers use another search strategy than inexperienced drivers, as they start the visual scanning further away from their vehicle. Since cyclists are often nearby, this can lead to dangerous situations as experienced drivers need more time to detect the cyclists. Second, experienced drivers may develop shorter search times and may extract only minimal information from the traffic scenes, based on expectancies about what they are likely to see. This is related to Endsleys' concept of automaticity: *short-circuiting the process of interpreting environmental cues, because pattern-recognition and action-selection can become highly routine* (Endsley, 2000). Endsley (2000) mentions the low level of attention that is required as an advantage, but also indicates that automaticity leads to dangerous situations. It is interesting to know how the algorithms of AVs will deal with this routine behavior. If the algorithms also show some sort of automaticity, based on previously experienced behavior, the same dangerous situations for cyclists will take place. If automaticity can be reduced, cyclist safety will increase.

Cycling experience
Another determinant related to experience, is cycling experience. Cycling experience is not only relevant for safety from the perspective of the cyclist, but also from the side of the driver. Maas (2011, as cited in Schepers et al. (2017)) indicated that motorists who cycle frequently are less likely to collide with cyclists. It is assumed that the experience of cycling aids drivers to anticipate on cyclists, because they know better where cyclists can be expected, and how they behave. Additionally, drivers that are more frequent cyclists show safer behavior towards cyclists: they drive significantly slower, and more to the left in their lane, which is more distant from bicycle lanes (Fournier et al., 2020).

To promote road safety between AVs and cyclists, this safe driver behavior towards cyclists can be included in AV programming. Another type of behavior that is observed by Fournier et al. (2020), is making eye glances. The authors showed that cycling frequency positively affects the proportion of drivers making eye glances. To increase the Situation Awareness of the driver, they monitor their environment better in search of (among others) cyclists. This behavior will be inherently included in AVs, as sensors are continuously scanning the environment looking for objects, and thus cyclists. However, it is important to realize that next to looking for cyclists (SA level 1), proper detection and classification of these cyclists (SA level 2) is detrimental to their safety.

Infrastructure familiarity
To increase cyclist safety, infrastructure is adjusted at certain intersections. Two examples are bike boxes and merge lanes (Figure 3.8). As described by Fournier et al. (2020), bike boxes provide a discrete space for cyclists, thereby minimizing the number of cyclists that are positioned in the drivers' blind spot while waiting for green. Merge lanes promote drivers to be aware of cyclists, in order to reduce the number of accidents due to drivers only focusing on vehicles when turning. Fournier et al. (2020) found that familiarity with these types of cyclist infrastructure positively affected driver behavior. Drivers more familiar with bike boxes stopped significantly further away from the bike boxes, and familiarity with merge lanes caused drivers to perform the merge maneuver earlier.



(a) Bike box (b) Merge lane

Figure 3.8: Bicycle infrastructure adjustments at intersections (Fournier et al., 2020)

However, no reasoning is given for this observed behavior. Based on the Situation Awareness theory of Endsley (1995), some suggestions can be made. Infrastructure familiarity reduces the complexity of a traffic situation, thereby increasing a drivers' SA. Additionally, when a driver is familiar with cyclist infrastructure, expectations are that cyclists can be expected. This familiarity ensures better comprehension of the situation (SA level 2), and a projection of future status includes possible cyclists (SA level 3). As a future status can include cyclists in the bike box, more distance is kept from the bike box (decision), to leave more space for the cyclists, improving road safety. Regarding the merge lanes, performing the merge maneuver earlier supposedly minimizes potential future conflicts when cyclists appear at a later moment in time (SA level 3).

Another type of infrastructure where the expectation of cyclists is important, is bi-directional bicycle lanes at roundabouts. If drivers are familiar with the infrastructure, they know it is a bi-directional lane, and consequently that cyclists can be expected from both sides. If drivers do not expect cyclists coming from the right side of the road, they may easily fail to see the cyclist, even if the driver looks in the direction of the cyclists (Rasanen & Summala, 2000). AVs need to be familiar with all different types of cycling infrastructure present, such that AVs know where cyclists can be expected, and behave accordingly to what cyclists expect.

For road authorities, such as the Provincie Noord-Holland, it is important to ensure that the infrastructure familiarity of AVs is tested and considered sufficiently safe, before permitting them on the roads. This holds for all different types of infrastructure that are present within the ODD of an AV.

3.2.4 Determinants Related to the Road Infrastructure

Another important aspect related to road safety between AVs and cyclists is the road infrastructure. Road infrastructure is closely related to exposure, especially the way in which cyclists are distributed over the road network, as discussed in Section 3.2.1. An overview of additional determinants related to the road infrastructure is presented in Figure 3.9, categorized in road sections and intersections. Most of the determinants are discussed in a generic way, discussing in which direction cyclist safety is affected. Chapter 4 will go more in-depth on cyclist safety at specific types of infrastructure.

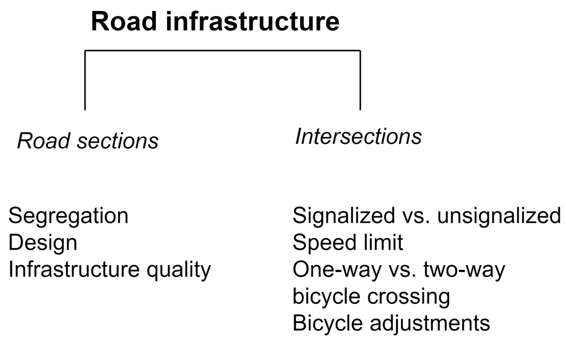


Figure 3.9: Determinants related to the road infrastructure

Road sections Three determinants related to road sections are discussed: cyclist preferences towards segregation (also referred to as separation), differences in the design of cycle lanes, and quality of the infrastructure.

Segregation
When cyclists are segregated from motor vehicles, exposure is reduced. This segregation is preferred by cyclists, as their subjective safety level is higher Heinen et al. (2010). Additionally, Vissers et al. (2016) found that especially older cyclists feel less safe when separate cycle paths are absent. According to Blau (2015), preference for segregated bicycle facilities grows with an increase in vehicle speed, volumes, and street width (in Parkin et al. (2016)).

Design
In the Netherlands, different designs for road sections are present. These different designs have different purposes, and even different laws and regulations (Fietsersbond, 2020). Two different bicycle lanes are displayed in Figure 3.10: an official bicycle lane (a) and an advisory bicycle lane, or bicycle suggestion lane (b). Although the noticeable differences are small, i.e. mainly the presence of a bicycle symbol at an official bicycle lane, their meaning is contrasting. Drivers may only cross the broken line of an official bicycle lane to reach an adjacent parking spot for example, but they are not allowed to stop or park on the bicycle lane. When the bicycle lane has a solid line, cars are never allowed to drive over it. On the other hand, drivers are at all times allowed to drive on an advisory bicycle lane. It is also possible to stop or park your vehicle at an advisory lane. A cyclist is also not obligated to cycle on these lanes, which might be conflicting for AVs. A suggestion lane is in particular meant to draw the attention of car drivers towards the potential presence of cyclists. Thereby, a suggestion lane is supposed to influence drivers' behavior and induce more respect for cyclists (Dufour, 2010). It is important for AVs to understand all different types of bicycle infrastructure and their associated laws and regulations. If not understood, this can create dangerous situations as actual AV behavior might differ from the behavior cyclists expect.

Another interesting design aspect is the coloring of bicycle lanes, to emphasize the presence of dedicated cycling infrastructure. A study by Hunter et al. (2000) shows that blue bicycle lanes resulted in mostly positive behavior: motorists yielded more often to cyclists, and more cyclists followed their intended path. On the other hand, fewer cyclists used hand signals to communicate their intentions (Hunter et al. (2000)), leading to a decrease in Situation Awareness. As can be seen in Figure 3.10, red is the most frequently used color for bicycle lanes in the Netherlands. No information was found on the color that would lead to the best detection by AVs.

Infrastructure quality
Another determinant related to road sections is the quality of the infrastructure. Uneven road surfaces are mentioned to be hazardous for cyclists, as they can make a sudden move towards motor vehicles (Basford et al., 2002). For AVs, infrastructure quality is even more important, to accurately detect cycling infrastructure. For Lane Assistance Systems, it is suggested to improve the quality and uniformity of lane markings to improve performance (Reddy et al., 2020). It is expected that improving the quality of bicycle lane road markings improves cyclist safety.

Figure 3.10: Different types of bicycle lanes: an official bicycle lane (a) and a bicycle advisory lane (b)

Intersections Intersections are especially interesting regarding cyclist safety, as the majority of current BMV accidents take place at intersections (Schepers et al., 2017). The determinants that will be discussed are signalized versus unsignalized intersections, speed limits, one-way versus two-way bicycle crossings, and bicycle adjustments.

Signalized vs. unsignalized
Dijkstra (2014) shows that per intersection, the number of accidents is larger for signalized intersections, compared to unsignalized intersections. This is observed both for the total number of accidents and accidents with Vulnerable Road Users (VRUs). Signalized intersections introduce the possibility for red-light running, which is found to be one of the major causes of accidents at these intersections (Kennisnetwerk SPV, 2019). At unsignalized intersections, the probability of a BMV accident is lower when the bicycle path is between two and five meters away from the main carriageway (Schepers et al., 2013). This separation of the bicycle path from the intersection is also advised by the newest CROW guidelines: the minimum distance should be five meters (Andriesse & van Gurp, 2020).

Speed limit
As discussed in Section 3.4, cyclists are increasingly separated from motor vehicles at higher speed limits. This significantly improves cyclist safety, as a reduction in vehicle speed is associated with reduced injury severity (Kim et al., 2007). According to Sustainable Safety principles, vehicle speed should be reduced to 30 km/h at conflict situations with cyclists. Schepers et al. (2017) mention that speed-reducing measures at unsignalized intersections have prevented approximately 2.5% of cyclist fatalities.

One-way vs. two-way bicycle crossing
It is concluded by Schepers et al. (2017) that additional risk factors for cyclist safety are present at two-way bicycle paths at intersections. Many accidents are caused by cyclists being overlooked by human drivers, causing a 75% increase in BMV accident risk compared to one-way bicycle paths (Schepers et al., 2011). However, Schepers et al. (2017) mentioned that two-way bicycle crossings are still safer compared to a road without cycling facilities. Due to continuously monitoring the environment, it is expected that cyclists are not being overlooked by AVs, thereby decreasing the difference in safety between one-way and two-way bicycle crossings.

Bicycle adjustments
To emphasize the presence of cyclists, bicycle adjustments are sometimes present at intersections. Three examples for signalized intersections are given by Schepers et al. (2017): advance stop lines, bike boxes, and separate signals ensuring a pre-start for cyclists. As discussed in Section 3.7, drivers' familiarity with bicycle adjustments positively affected their behavior towards cyclists (Fournier et al., 2020). For AVs, these bicycle adjustments can increase Situation Awareness by indicating an increased probability of encountering cyclists.

3.2.5 Determinants Related to Automated Vehicles

In the conceptual framework of Schepers et al. (2017), determinants related to vehicles were discussed only briefly. In particular, the focus was on the design of bicycles. For a situation with AVs, the characteristics of these AVs and the related determinants affecting safety are very important to determine how AVs will affect cyclist safety. The categories of determinants related to AVs that are discussed are technology, communication, and determinants related to cyclists. A visualization of the determinants related to Automated Vehicles is provided in Figure 3.11.

A note needs to be made that new situations will arise leading to dangerous situations. However, it is difficult to project which new situations will arise, and how AVs are able to tackle emerging problems. This is not taken into account in this section, but will be discussed briefly in Section 7.

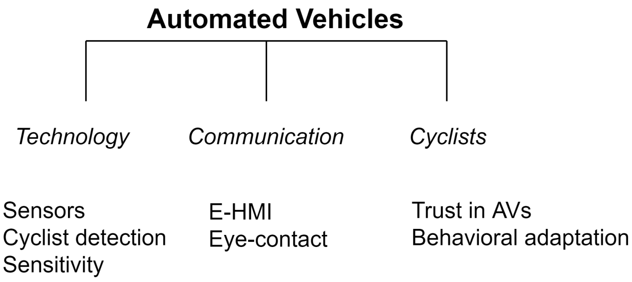


Figure 3.11: Determinants related to Automated Vehicles

Technology Technology is the key aspect of Automated Vehicles and it is evident that AV technology needs to be satisfactory to safely interact with cyclists. The determinants related to technology that will be discussed are sensors, cyclist detection, and sensitivity of the AV settings.

Sensors
Where human drivers use visual perception, AVs are equipped with a diversity of sensors to create Situational Awareness. Often used sensor types are cameras (both visible spectrum and infrared), RADAR, and LIDAR (Mannion, 2019). As every type of sensor has its weaknesses, typically different sensor types are combined on AVs (Mannion, 2019). Tesla is one of the few companies that does not use LIDAR sensors to achieve full self-driving capabilities in the future and mainly relies on visual perception (Tesla, 2020).

A comparison of different sensor types is provided in Table 3.1, reproduced from Ahmed et al. (2019). As can be seen, every sensor type has its own benefits and drawbacks. Visual sensors capture high-resolution images, providing a lot of information on the environment. However, large drawbacks are decreased performance in low-light conditions and due to occlusion. Furthermore, cyclist detection is said to be more difficult than pedestrian detection, due to greater variability of possible orientations (Ahmed et al., 2019). Thermal cameras are not affected by illumination levels, but are more expensive than visual cameras and are affected by temperatures. An important note from Ahmed et al. (2019) is that clothing can affect a cyclists' thermal footprint, making thermal sensors not very effective. RADAR and LIDAR are not affected by temperature, and accurately measure distance towards cyclists. Whereas both RADAR and LIDAR have a reduced resolution than visual and thermal sensors, they perform better in low-light conditions. LIDAR sensors have the best performance in adverse weather conditions. However, LIDAR sensors are also by far the most expensive. Furthermore, both RADAR and LIDAR are affected by elevation in the environment.

Table 3.1: Sensor comparison for vulnerable road user detection, reproduced from Ahmed et al. (2019)

Criteria	Visual	Thermal	RADAR	LIDAR
Resolution	good	good	fair	fair
Illumination	poor	good	good	good
Weather	fair	good	fair	good
Elevation	good	good	poor	poor
Temperature	good	fair	good	good
Cost	good	fair	poor	poor

Combining different types of sensors to improve performance, known as sensor fusion, is often used for AVs (Ahmed et al. (2019); Mannion (2019)). Sensor fusion will also increase Situation Awareness towards cyclists. As indicated by

Schoettle (2017), RADAR and LIDAR are best for object detection, whereas cameras are best for object classification. Based on the benefits and weaknesses shown in Table 3.1, sensor fusion is desired for accurate cyclist detection and classification in all possible scenarios.

Cyclist detection
If AVs are to interact with cyclists, it is evident that cyclist detection needs to be accurate. All literature found came to the same conclusion: cyclist detection is not yet sufficiently accurate (e.g. Botello et al. (2019); Mannion (2019); Braun et al. (2018)). This might give an erroneous view of reality, as Original Equipment Manufacturers (OEMs) do not share all their data and technology is improving rapidly. However, it indicates that cyclist detection accuracy is an important challenge. Botello et al. (2019) found that expert interviewees, who expected AVs to have a positive impact on cyclists, were concerned about the detection and prediction capabilities of AVs. Botello et al. (2019) furthermore state that the current detection rate of cyclists is too low, and if cyclists are detected, their movement is not accurately predicted. Some interviewees expressed additional concerns for detection capabilities during the night or adverse weather conditions. However, none of the respondents thought the detection problem is insurmountable in the long-term. It is also advocated that the government needs to set standards for cyclist detection and prediction (Botello et al., 2019). Mannion (2019) mentions multiple challenges related to VRU detection, which is as a whole mentioned as one of the most challenging tasks for AVs. Partially occluded objects are one of these problems, as it is difficult for an AV to detect a VRU that is not fully visible (Gilroy et al., 2019). When fully occluded, such as behind another vehicle, a building, or another VRU, all line-of-sight AV perception systems are not able to detect VRUs (Mannion, 2019). When AVs are connected to other vehicles, infrastructure, or VRUs, the number of occlusions could be reduced. Another challenge mentioned by Mannion (2019) is the detection of VRU gestures. As discussed in Section 3.5, both formal and informal gestures are used by cyclists to communicate their intentions. Mannion (2019) states that at least often used gestures need to be interpreted correctly by AVs, such as signals indicating a change of direction. Correctly interpreting these gestures is needed to model and predict VRU behavior. Furthermore, reducing the rate of false positives is mentioned as a challenge. Mannion (2019) states that especially VRU detection presents possibilities for false positives, such as *"reflections, clothes displayed in shop windows and large advertisements in the scene background which feature people"* (p. 3).

Sensitivity
Another determinant related to AV technology is sensitivity of the AV settings. A higher sensitivity of an AV results in more conservative behavior. To prevent accidents in the early stages of AV deployment, it is expected that AVs behave conservative (e.g. Hartmann et al. (2017); Schwarting et al. (2019)). This is illustrated by Parkin et al. (2016) given an interaction scenario between an AV from Google and a cyclist. Although the AV had right of way at an intersection, it could not accurately predict the intentions of the cyclist and decided to stand still for two minutes. More conservative driving behavior can reduce collisions directly caused by the AV, but leads to other problems. Among others, conservative behavior reduces capacity (Hartmann et al., 2017), and creates bottlenecks in traffic flow, especially at intersections (Schwarting et al., 2019). Schwarting et al. (2019) mention that Waymo, which the authors consider a leader in autonomous driving, still has difficulty with left turns at intersections. Additionally, the authors stated that in most of the accidents involving AVs in California, the AV is rear-ended by human drivers. Schwarting et al. (2019) concluded that many of these accidents happened due to unexpected actions of the AV due to conservative behavior, leading to human drivers not being able to anticipate. This means that conservative behavior of AVs can result in unexpected behavior, indirectly leading to accidents. Therefore, too conservative behavior of AVs should be avoided. For the interaction with cyclists, it means that AVs should be able to accurately predict cyclist intentions when cyclists can be encountered within the ODD. Otherwise, unnecessary deceleration can lead to a rear-end accident with the succeeding HDV.

Communication To increase Situation Awareness in traffic, it is important to communicate intentions to other road users. AVs can communicate to other road users via an External Human Machine Interface (E-HMI), which will be discussed first. It is furthermore found that eye-contact with the passenger in an AV is found to be influencing the interaction with AVs.

External Human Machine Interface (E-HMI)
As found by Fuest et al. (2018), an AV can use its driving behavior to communicate its intentions regarding right of way. They stated that pedestrians understand AV intentions based on their speed and deceleration rate, also in shared

space situations. However, both pedestrians and cyclists appreciate additional communication of AVs by messages or signals indicating their intentions (Vissers et al., 2016). This can be done via an E-HMI. For a proper functioning E-HMI, four design considerations are described by Schieben et al. (2019). It is important that an E-HMI gives information on vehicle driving mode, maneuvers, perception of the environment, and cooperation capabilities. Schieben et al. (2019) furthermore stated there is no E-HMI that takes into account all these design considerations and applies to all traffic situations and vehicle types. Although much research is going on in the field of E-HMIs, this is not covered in detail in this study. Different E-HMI concepts are mentioned and reviewed extensively in e.g. Bazilinskyy et al. (2019) and Dey et al. (2020).

Eye-contact
In a study on pedestrian crossing behavior at zebra crossings, Lundgren et al. (2017) found that eye-contact with the person in the driver seat of an AV influences pedestrian behavior. When the driver is inattentive, for example when talking to the phone or reading a newspaper, pedestrians are less willing to cross the street. Most pedestrians indicated that having eye-contact with the driver influenced their decision whether or not they would cross the street. Although the study focused solely on pedestrians, it is expected that similar behavior will be observed for cyclists, as eye-contact is also used by cyclists to create Situation Awareness (Westerhuis & de Waard, 2017). This can lead to a potential problem specifically for AVs, if different behavior is executed than what the person in the driving seat might imply.

Cyclist From a cyclist perspective, two determinants are discussed directly related to AVs. First, the level of trust cyclists have in AVs and its implications are discussed. Second, it is likely that cyclists will adapt their behavior when interacting with AVs, which is discussed afterward.

Trust in AVs
Vissers et al. (2016) found, based on the few studies existing in 2016, that pedestrians and cyclists were not confident of the skills of an AV, leading to cautious behavior. This is confirmed by Hagenzieker et al. (2020), who found that participants of a photo experiment were more confident to be noticed by a conventional vehicle than by an AV. In a video experiment, Vlakveld et al. (2020) found similar results: although having right of way, participants yielded more often for AVs compared to HDVs. Vlakveld et al. (2020) also found that this yielding behavior appeared more often when participants watched a negative introductory video before the experiment. This shows that the level of trust influences yielding behavior of cyclists, as a lower trust in technology resulted in more conservative behavior. The level of trust or confidence in AVs is closely related to perceived safety. Even if AVs are safer than HDVs, cyclists can have the feeling that it is less safe. It is important that AVs do not decrease the perceived safety level of cyclists, making it less attractive to cycle.

Behavioral adaptation
As mentioned before, the level of trust in AVs influences cyclist behavior. This can of course differ between people, as the levels of trust can be very diverse. Eventually, cyclist behavior is likely to be different, depending on whether the interaction is with an AV or an HDV (Vissers et al., 2016). However, it is difficult to predict what the direction of behavioral adaptation will be, as this can be either more risk-averse or more risk-taking. As discussed before, yielding for AVs while having right of way is an example of more risk-averse behavior (Vlakveld et al., 2020). On the other hand, more risk-taking behavior can lead to accepting smaller gaps when crossing in front of an AV, or red-light running, because it is expected that AVs are able to stop in time (e.g. Millard-Ball (2018); Vissers et al. (2016)). Vissers et al. (2016) furthermore mention current behavioral patterns are thus not sufficient for the algorithms of an AV. Additionally, behavioral adaptation can also differ between people, making it even more difficult for AVs to predict cyclist intentions.

3.3 Synthesis of the Results

This section provides a synthesis of the results from the literature review, as discussed in Section 3.2. Based on the conceptual framework of Schepers et al. (2017), as illustrated in Figure 3.3, a conceptual framework on factors affecting road safety between AVs and cyclists is presented in Figure 3.12. The relationship between all factors is discussed afterward, based on the Situation Awareness theory of Endsley (1995). The determinants expected to affect road safety between AVs and cyclists the most, based on literature, are included in Figure 3.12 and are discussed separately.

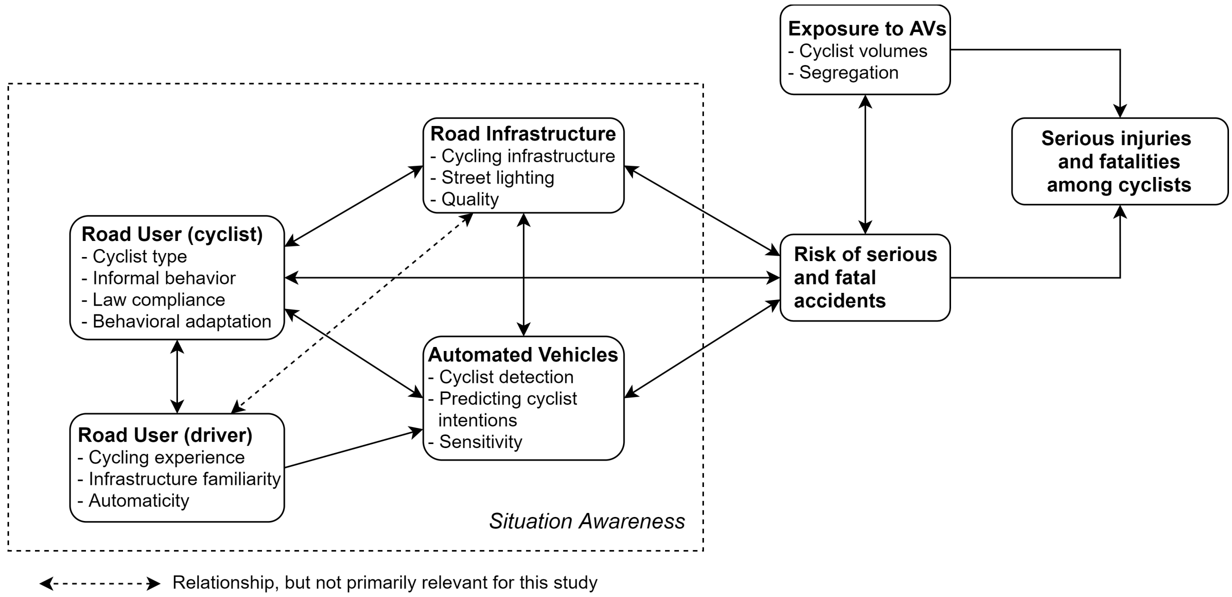


Figure 3.12: Conceptual framework on factors affecting road safety between AVs and cyclists, including the most important determinants

Road user (driver) If a cyclist does not recognize an AV, the cyclist will respond to an AV as it would respond to an HDV. It is therefore important that the behavior of AVs is comparable to that of HDVs, such that cyclists can correctly project their future status. Additionally, safe driver behavior towards cyclists should be incorporated in AVs. Cycling experience and infrastructure familiarity of human drivers are found to positively affect cyclist safety, by more conservative behavior towards cyclists. On the other hand, negative driver behavior towards cyclists should be omitted in AVs as much as possible. An example is automaticity, where Situation Awareness is reduced due to routine behavior caused by driver experience.

Road user (cyclist) The behavior of cyclists is of course important for cyclist safety, especially the link between cyclists' behavior and AVs. Cyclist behavior is non-homogeneous, which is found to be even larger between different cyclist types. It might be valuable if AVs can distinguish cyclist types and project different future statuses based on cyclist type. A type of behavior that is difficult for AVs is informal behavior. Cyclists often do not follow the formal traffic rules, possibly leading to an incorrect projection of future status by an AV. The same is observed for law compliance: it is found that cyclists regularly show violating behavior. Examples of violating behavior possibly causing dangerous situations are alcohol use, mobile phone use, and red-light running. Finally, cyclists may adapt their behavior, depending on whether the interaction is with an AV or HDV. This can be either more risk-taking or more risk-averse and will even be different between people.

Automated Vehicles The complexity in cyclist behavior increases the difficulty for AVs to correctly assess Situation Awareness for all three levels. It is found that current cyclist detection capabilities of AVs are not yet sufficient, especially in darkness or adverse weather conditions. It is worth noticing that human drivers also frequently fail to detect cyclists in these conditions. Furthermore, correctly predicting a cyclists' intention (and thus future status) is difficult, especially as formal signals to communicate intentions are often not used by cyclists. Another important determinant related to AVs is sensitivity: conservative behavior towards cyclists can increase safety. However, AVs should not be too conservative, as that is found to lead to rear-end collisions by succeeding HDVs.

Road infrastructure It is important that road infrastructure is clear and predictable. Clear cycling infrastructure enlarges Situation Awareness, as it is emphasized where cyclists can be expected. Additionally, the infrastructure quality should be sufficient, such that all relevant elements are perceived by AVs (i.e. road signs and road surface markings). Finally, the effect of street lighting for cyclist detection is important. An interesting safety paradox is present, as street lighting improves cyclist visibility, but decreases AV functionality due to reduced detection of road surface markings.

Exposure to AVs The interaction between the previously mentioned factors leads to an increase or decrease in the risk of serious and fatal accidents. The actual number of serious injuries and fatalities among cyclists is determined by the combination of this risk with exposure. The exposure between cyclists and AVs is largely dependent on cyclist volumes: if more cyclists are encountered, the same risk level will lead to more accidents. If exposure is reduced, fewer accidents will happen. In current street hierarchies, cyclists are increasingly segregated from vehicles by an increase in speed limit. Exposure can be limited by segregating cyclists from AVs, either visually or physically.

3.4 Hypotheses to Promote Road Safety Between Automated Vehicles and Cyclists

Based on the literature review and the synthesis of the resulting determinants affecting road safety, multiple hypotheses to promote road safety between AVs and cyclists are formulated. The hypotheses are divided into three categories: from the perspective of the cyclist, the AV, and the infrastructure. Hypotheses are often related to multiple categories and placed under the category related most to the hypothesis.

3.4.1 Cyclist Perspective

1. *Different AV response to different types of cyclists leads to safer AV/cyclist interaction, due to better prediction of the cyclists' behavior*

Cyclist behavior is non-homogeneous with large differences between different types of cyclists. Within these types, the behavior is also non-homogeneous, but to a lesser extent. For a safe interaction, a correct projection of the future status of a cyclist must be predicted. However, the expected future status might differ between different cyclist types, which makes it harder for AVs to accurately predict the behavior of a cyclist. If cyclists are classified in different types, and future status is projected accordingly to the expected behavior of this specific cyclist type, it is expected that the prediction is more accurate. However, it will be challenging to determine which specific cyclist types will be used for classification, as there are many different classifications throughout literature. Furthermore, it is unknown to what extent it will be possible for AVs to classify a cyclist type, as it is already difficult to correctly detect and classify cyclists.

2. *AVs need to take into account informal cyclist behavior for a safer AV/cyclist interaction*

Cyclists, as well as human drivers, do not always follow the formal traffic rules: here referred to as 'informal behavior'. It happens quite often that cyclists do not have right of way, but get it. Vice versa, sometimes a cyclist has right of way, but does not use it. Examples of these situations are the following:

- Cyclists taking right of way at a zebra crossing
- Cyclists taking right of way in rainy conditions
- Cyclists giving right of way to a vehicle to improve traffic flow

When an AV always behaves according to formal traffic rules, this can lead to dangerous situations. To increase safety when interacting with cyclists, it is important that an AV can take into account informal cyclist behavior. The first step is that an AV knows when cyclists might behave informal, to better predict their intentions. The second, more difficult step is to determine when to behave in an informal way.

3. *Cyclists will adjust their behavior when interacting with AVs towards more risky behavior, leading to dangerous situations*

Cyclists may change their behavior when interacting with AVs. This can either be more cautious when cyclists do not trust the AV technology, or more dangerous when cyclists fully rely on technology. This will also differ between cyclists. It is expected that cyclists will show more risky behavior, as that is what is suggested by most studies found during the literature review. Vissers et al. (2016) for example stated running red lights and acceptance of smaller gaps when crossing the road as possible dangerous behavior, because cyclists would expect the AV would notice them and stop in time.

The difficulty is that it is not possible to derive actual cyclist behavior when AVs are not interacting with cyclists in real traffic situations. It is only possible to derive stated behavior, which can be different from actual behavior. It is furthermore questionable whether AVs are clearly recognized by cyclists or not.

4. *Cyclists' smartphone data can be used to communicate with AVs, leading to fewer conflicts due to increased detection and classification of cyclists*

Detection and classification of cyclists are mentioned as a challenge for AVs. It is expected that smartphone data of cyclists can be useful to communicate their presence or their intentions. This will supposedly lead to fewer conflicts, as cyclists are easier detected by AVs, which could especially be a solution in adverse weather conditions. It can also prevent potential collisions caused by occluded cyclists (Bieshaar et al., 2018). Additionally, turning intentions of cyclists might be communicated to AVs, when the cyclist uses an application for navigation.

3.4.2 Automated Vehicle Perspective

5. *Integrating safe driver behavior towards cyclists in AV programming leads to safer AV/cyclist interaction, due to conservative settings*

In literature, it is found that drivers having experience as a cyclist, behave differently when interacting with cyclists. For example, they make more eye glances at treatments, drive significantly slower and more to the left in the proximity of cyclists, and maintain a greater overtaking distance (Fournier et al., 2020). It is suggested that this conservative behavior towards cyclists is experienced because they would prefer the same driver behavior when cycling. It is expected that the safety between AVs and cyclists will increase if this conservative behavior is copied in AVs. Additionally, cyclists' trust in AVs will increase because cyclists perceive the interaction as more pleasant.

A challenge is to determine to what extent an AV should be conservative towards cyclists, as too conservative behavior can lead to other dangerous traffic situations. An example can be that an AV decides not to overtake a cyclist due to limited space, leading to annoyance for succeeding HDVs.

6. *AVs cannot yet accurately detect and classify cyclists in all situations, leading to dangerous AV/cyclist conflicts*

For human drivers, it is harder to detect cyclists in adverse weather conditions or during the night, especially without proper bicycle lights. For AVs, the same difficulties are expected, especially because the cameras and sensors have reduced functionality in these situations. Examples of situations where proper cyclist detection is questionable are the following:

- During the night, deteriorated without proper bicycle lights
- In bad weather conditions, such as rain, fog, dusk and, snow
- In sunny conditions, causing sun glare

Additional insights into the capabilities of cyclist detection in non-ideal scenarios are needed to guarantee adequate cyclist detection at all times.

7. *AVs cannot yet accurately predict turning intentions of cyclists, leading to dangerous AV/cyclist conflicts*

Cyclists are supposed to communicate their turning intentions by using arm signals, but they often fail to do so. Human drivers try to predict turning intentions of cyclists based on many other visual cues, such as head checks, speed, position on the road, speed change, and position on the bike (Hemeren et al., 2014). However, it is still difficult to predict cyclists' turning intentions (Westerhuis & de Waard, 2017). It is expected that, with current technologies, AVs are not yet able to predict cyclists' turning intentions sufficiently accurate to guarantee safety (Botello et al., 2019).

8. *Increased AV sensitivity in specific situations leads to fewer AV/cyclist conflicts*

Similar to existing traffic situations, AVs will never be able to eliminate all accidents, due to the complexity of traffic. Even when AV technology is sufficiently safe to operate on public roads, there will always be certain situations or locations that are more likely to lead to accidents. If these specific situations are known, it is expected that conflicts can be avoided if the sensitivity of AVs is increased at these situations or locations. This means for example that an AV slows down or takes into account an increased probability of anomalous cyclist behavior.

Examples of situations and locations that are expected to have a higher chance of conflicts between AVs and cyclists are:

- Start and end of a cyclists' red-light cycle, especially at specific junctions with more red-light runners

- Cyclists' during the early night, due to increased probability of alcohol use
- Specific dangerous locations, such as locations with multiple accidents in the past

Although this increased AV sensitivity might lead to fewer conflicts, there are ethical issues. It is questionable if it is acceptable to design for inabilities and traffic violations of cyclists. Furthermore, if this increased sensitivity is known by cyclists, their behavior might become more dangerous, thereby decreasing safety.

9. *Adding desire lines of cyclists to AV algorithms, leads to fewer AV/cyclist conflicts, due to better prediction of cyclists' trajectory*

Cyclists do not always follow the path they are supposed to follow. Desire lines are cyclist paths that deviate from the designed path based on the infrastructure. Figure 3.13 shows actual cyclist behavior at an intersection in Amsterdam, showing many different paths cyclists use (te Brömmelstroet, 2014). Human drivers might expect this behavior, possibly based on their own experience as a cyclist, but AVs might not. These deviations currently happen mostly with social interactions, which is more difficult in a situation with AVs. It is expected that if AVs are aware of these alternate path choices, it will lead to fewer situations where a cyclist is not expected by an AV.

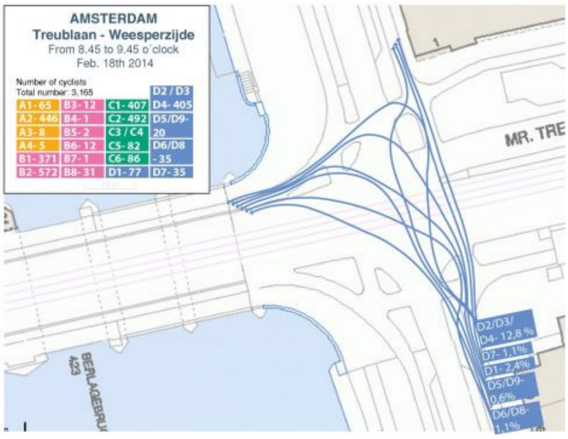


Figure 3.13: Example of cyclist Desire Lines (te Brömmelstroet, 2014)

3.4.3 Road Infrastructure Perspective

10. *More uniformity and predictability in infrastructure leads to safer AV/cyclist interaction, because less communication is needed to understand each other's behavior*

If many different designs of similar types of infrastructure are present close to each other, this can lead to lower understandability of the situation. For example, if different roundabout designs with different right of way situations are close to each other, this can lead to ambiguity. To diminish ambiguity, infrastructure guidelines are established by CROW, proposing ideal designs of infrastructure for different situations. Uniformity in traffic situations is also advocated in Sustainable Safety guidelines (SWOV, 2018), stating that similar infrastructure designs in similar situations ensure that people recognize the right context for their behavior.

However, it is not always the case that the guidelines for infrastructure design are followed, due to various reasons such as high costs or lack of space. It is expected that if the infrastructure is more uniform, it is clearer for both AVs and cyclists what to expect at e.g. junctions or roundabouts.

11. *Clear cycling infrastructure ensures better understandability of the AV, leading to safer AV/cyclist interaction*

In an ideal situation, AVs and cyclists are at all times physically segregated. As that is not always possible, visually segregating vehicles and cyclists is also possible. However, visually segregated cycling infrastructure is not always present, meaning that cyclists and AVs will need to share the road at some locations. When sharing the same road, it is expected that it is more difficult for AVs to be able to understand where to expect cyclists and what behavior to expect from cyclists. Therefore, clear cycling infrastructure separating AVs from cyclists is expected to lead to better Situation Awareness of AVs. Examples of clear cycling infrastructure are bicycle lanes or advisory bicycle lanes, desirably painted in a different color.

12. *Despite less visible road lines, street lighting increases cyclist visibility and thus detection, leading to fewer AV/cyclist conflicts*

On the one hand, street lighting ensures better visibility of cyclists. On the other hand, street lighting diminishes the visibility of road lines (Reddy et al., 2020). This leads to a paradox, where safety is increased by being able to detect a cyclist better, while safety is decreased due to less visible road lines resulting in possible lane deviations of the AV. It is not known which of these effects is stronger. It is expected that the safety increase due to improved cyclist detection is significantly higher.

3.5 Conclusions

Situation Awareness (SA) is an important basis for road safety. By correctly interpreting the state of the environment, including interaction with other road users, Situation Awareness can be increased, leading to improved road safety. The three different levels of SA, as introduced by Endsley (1995), can be translated to AVs, as shown in Table 3.2. With the introduction of AVs, new challenges for all levels of SA will arise. For the first level, the number of false positives and negatives needs to be minimized to correctly detect all objects. For the second level, all important elements need to be recognized, while all unimportant elements are ignored. For the third level, the intentions of cyclists need to be understood to correctly project their future status. As AV technology is not yet proven to be sufficiently safe, questions remain on AV capabilities regarding cyclist detection, classification, and trajectory prediction.

Table 3.2: Different levels of Situation Awareness for human drivers and Automated Vehicles

	Human drivers (Endsley, 1995)	*Automated Vehicles*
Level 1	Perception of the elements in the environment	Object detection
Level 2	Comprehension of the current situation	Object classification
Level 3	Projection of future status	Object trajectory prediction

Incorrect assessment of Situation Awareness, either by an AV or cyclist, leads to an increased risk of accidents. It is found that cyclist intentions are difficult to predict (SA level 3). Different types of cyclists can be identified, leading to non-homogeneous behavior. For AVs, it will be difficult to project the future status of a cyclist, if multiple scenarios are possible based on cyclist type. Additional difficulties are informal and violating behavior of cyclists: it is not known to what extent AVs can deal with these types of anomalous behavior. Furthermore, behavioral adaptation of cyclists towards AVs is possible, leading to either more risk-averse or more risk-taking behavior.

Driver behavior is an important factor that can be used as input for AV programming. Incorporating positive driver behavior towards cyclists, resulting from experience as a cyclist and infrastructure familiarity, can increase safety by having more conservative settings. On the other hand, negative driver behavior, such as automaticity, needs to be omitted in AVs where possible.

Determinants related to AVs, cyclists, and road infrastructure all contribute to an increased accident risk. Together with exposure, this risk leads to actual accidents. Physically segregated infrastructure is desired to minimize exposure between AVs and cyclists. However, that is not always possible due to e.g. increased cost or lack of space. Therefore, there are many different types of existing infrastructure with exposure to cyclists that an AV needs to deal with, such as different types of bicycle lanes, roundabouts, and intersections.

Based on the findings from the literature review, hypotheses to increase road safety between AVs and cyclists are formulated. This is done from the perspective of cyclists, AVs, and road infrastructure; an overview of which is given in Table 3.3.

Table 3.3: Hypotheses to promote road safety between AVs and cyclists

Cyclist perspective	*Automated Vehicle perspective*	*Road infrastructure perspective*
1. Take into account cyclist type 2. Take into account informal behavior 3. Anticipate on behavioral adaptation 4. Use smartphone data for communication	5. Integrate safe driver behavior 6. Improve cyclist detection in adverse situations 7. Improve prediction of cyclists' turning intentions 8. Increase sensitivity in specific situations 9. Add desire lines to AV algorithms	10. Increase uniformity and predictability in infrastructure 11. Increase clear cycling infrastructure 12. Increase street lighting

Highlights

- Challenges in Situation Awareness of AVs are present for all three levels: cyclist detection, classification, and trajectory prediction
- Cyclist behavior is difficult to predict, e.g. caused by different cyclist types, informal behavior, law incompliance, and possible behavioral adaptation towards AVs
- Incorporating safe driver behavior towards cyclists in AV programming can increase cyclist safety by having more conservative settings
- To minimize exposure and thereby the number of accidents, cyclists should be physically segregated from AVs

4 Bicycle-Motor Vehicle Safety

This chapter presents more detailed information on cyclist safety. To give more background on current cyclist safety, current bicycle-motor vehicle accidents are analyzed in Section 4.1 and important risk factors are highlighted. Afterward, Surrogate Measures of Safety to assess road safety are discussed in Section 4.2. First, currently used Surrogate Measures of Safety are discussed, which are then translated to a situation with Automated Vehicles (AVs). Based on these Surrogate Measures of Safety and accident details, potential conflict situations for AVs and cyclists are presented in Section 4.3. Finally, the conclusions of this chapter that are relevant for the remainder of this study are presented in Section 4.4.

4.1 Bicycle-Motor Vehicle Accidents

As stated in Chapter 1, the number of bicycle fatalities in the Netherlands has been fairly constant over the past years, while the total number of road fatalities has decreased. As found by SWOV (2017), important risk factors leading to accidents are unsafe behavior of cyclists themselves (e.g. red-light running, smartphone use, cycling under the influence, and cycling without proper bicycle lights) and unsafe behavior of other road users (speeding, distraction, red-light running, and drink-driving). This section describes the findings of traffic safety institutes after analyzing Dutch bicycle accident data. The results are focused on collision partners and infrastructure types. More recent data is not elaborately discussed in similar reports, but will be discussed in Section 4.1.2.

4.1.1 Accident Data from Dutch Safety Reports

Most of the fatal bicycle accidents are collisions with motor vehicles (Reurings et al., 2012). This is displayed in Table 4.1, enumerating the number of bicycle-motor vehicle (BMV) accidents and non-BMV accidents in the years 2000-2009. It can be seen that the large majority of fatal bicycle accidents are a collision with a motor vehicle. The given numbers are all fatalities registered in the BRON database. Multiple types of motor vehicles are included in these numbers. For the years 2005-2009, a division is made over different types of motor vehicles, as shown in Table 4.2. It can be seen that the majority of motor vehicle collision partners are passenger cars, in particular for serious injuries and Emergency Room (ER) admissions. When colliding with a truck or bus, relatively many accidents lead to cyclist fatality. This is logical due to the reduced compatibility in terms of mass and size, which leads to a decrease in safety for vulnerable road users (SWOV, 2018).

Table 4.1: Number of bicycle-motor vehicle (BMV) accidents versus non-BMV accidents (Reurings et al., 2012)

Year	BMV accidents	Non-BMV accidents
2000	180	17
2001	183	11
2002	145	22
2003	163	24
2004	140	17
2005	139	12
2006	161	18
2007	131	16
2008	128	17
2009	119	19

Additionally, Reurings et al. (2012) looked at the number of accidents for different types of infrastructure. A questionnaire was sent to cyclists who visited the Emergency Room (ER), among others asking where the accident took place. As shown in Table 4.3, 30% of accidents occurred at a priority intersection. The most common accidents at priority intersections are collisions with cross traffic (a cyclist crossing a main road) or through traffic (a cyclist driving along a main road and crossing a side street). Accidents at these intersections are often caused by inattention of the other road user, or cyclists taking right of way while having to yield (Reurings et al., 2012). At non-priority intersections, which is mostly in 30 km/h

Table 4.2: Number of bicycle casualties per collision partner from 2005-2009 (Reurings et al., 2012, p.84)

	Fatalities*		Serious injuries		ER-admissions**	
	Number	Share	Number	Share	Number	Share
Passenger car	361	53%	5,542	69%	39,500	80%
Delivery van	95	14%	833	10%	950	2%
Truck/bus	152	22%	452	6%	1,950	4%
Motor	14	2%	150	2%	1,250	3%
Moped	11	2%	838	10%	6,000	12%
Other	45	7%	176	2%	-	-
Total	678	100%	7,992	100%	50,000	100%
** Only fatalities registered in BRON*						
*** Estimation*						

zones, car drivers better adhere to the right of way rules compared to priority intersections (Berends & Stipdonk (2009), in Reurings et al. (2012)). For cyclists, no significant difference is found between these types of intersection.

According to the questionnaire of Reurings et al. (2012), 9% of BMV accidents took place at a signalized intersection. Two of the most common accident types at signalized intersections are caused by not giving priority at permitted conflicts, and red-light running, both consciously and unconsciously (Kennisnetwerk SPV, 2019). It is advised that there are no permitted conflicts between turning vehicles and cyclists going straight, especially in case of a two-way cycle path. Furthermore, bicycle-friendly measures are advised by Kennisnetwerk SPV (2019) to prevent red-light running. Examples are simultaneous green times for all cyclist directions and ensuring sufficient space for waiting cyclists.

Table 4.3: Share of bicycle-motor vehicle (BMV) accidents per type of infrastructure: self-reported by cyclists involved in BMV accidents (Reurings et al., 2012)

Type of infrastructure	**Share of BMV accidents**
Straight road section	29%
Curved road section	9%
Signalized intersection	9%
Priority intersection	30%
Non-priority intersection	17%
Roundabout (cyclists having priority)	3%
Roundabout (cyclists having no priority)	2%

The numbers in Table 4.3 are not corrected for how often a situation occurs. Dijkstra (2014) analyzed some of the situations from Table 4.3 in more detail by taking into account the frequency of occurrence. The number of serious injury accidents, both in total and with vulnerable road users, is calculated per junction per year. The results for junctions outside city limits are shown in Table 4.4. From this analysis, it can be concluded that the density for both total accidents as VRU (Vulnerable Road User) accidents is highest at signalized intersections. Signalized intersections where the traffic volume of the crossing road is more than 40% of the main road are in particular unsafe (Dijkstra, 2014). When looking at different road categories, the share of cyclists involved in accidents is highest at intersections of higher-order roads.

Similar to Table 4.3, roundabouts also score best in terms of accident density per junction. An important reason for the safety at roundabouts is the low number of conflict points. Furthermore, contrary to signalized intersections and priority intersections, there is a speed reduction at all conflict points (Dijkstra, 2014).

Table 4.4: Number of serious injury accidents per junction type per year (Dijkstra, 2014)

Type of infrastructure	**Total accidents**	**VRU accidents**
Signalized intersection	6.50	1.80
Priority intersection (3-legged)	3.4	0.98
Priority intersection (4-legged)	4.5	1.16
Roundabout	1.5	0.34

A more detailed analysis of cyclist safety at roundabouts with recent data (2015-2018) is conducted by CROW (2019). It is found that approximately 2% of bicycle accidents happen at roundabouts, meaning roundabouts are the safest type of junction. Different types of roundabouts have different safety levels. Roundabouts within city limits with cyclists having priority have an average of 0.73 bicycle accidents per roundabout (from 2015-2018). At roundabouts within city limits with cyclists having no priority, an average of 0.18 bicycle accidents per roundabout (from 2015-2018) is found. Although slightly more bicycle accidents occur at roundabouts with cyclists having priority, it is still the preferred option within city limits (CROW, 2019). The main reasons given are to stimulate bicycle use and to create uniformity in design, leading to predictable behavior.

Although an exact number is not given, it can be deduced from the other numbers that roundabouts outside city limits have a maximum of 0.21 bicycle accidents per roundabout in the period 2015-2018.[5] According to the CROW guidelines, roundabouts outside city limits are almost always with cyclists having no priority (SWOV, 2012). The data of CROW (2019) is not corrected for cyclist and vehicle traffic volumes, which is suggested as a possible reason for the larger number of bicycle accidents at roundabouts within city limits.

4.1.2 Analysis of Recent Dutch Accident Data

Most of the numbers from Section 4.1 are somewhat outdated, as most of the reports analyzing BMV accidents do not include recent years. Therefore, an analysis is conducted for more recent accidents. The BRON dataset is used, including all traffic accidents documented by the police or road inspectors. Accident data of 2010-2019 is used, filtered for fatal and serious BMV accidents only. In total, 21.687 accidents were reported, of which 655 fatalities (3.0%) and 21.032 serious injuries (97.0%). As can be seen in Table 4.5, the majority of BMV accidents were reported within city limits. The total of (at least) 16.466 serious accidents over the past ten years confirms the complex cycling environment that is present within city limits. Another interesting finding shown in Table 4.5 is the share of fatalities outside city limits. Over 10% of the accidents outside city limits result in a cyclist fatality.

Table 4.5: Number of fatal and serious injuries within and outside city limits (data: BRON 2010-2019)

Accident location	Fatalities (%)	Serious injuries %	Total
Within city limits	388 (2.4%)	16.078 (97.6%)	16.466
Outside city limits	237 (10.3%)	2.073 (89.7%)	2.310
Unknown	30 (1.0%)	2.881 (99.0%)	2.911
Total	655 (3.0%)	21.032 (97.0%)	21.687

This large share of fatalities outside city limits is among others caused by a higher speed limit. In general, the speed limit within city limits is at most 50 km/h. As shown in Table 4.6, the share of fatalities significantly increases with a higher speed limit. Only 2.3% of the accidents with a speed limit of 50 km/h results in a fatality, which is even less for 30 km/h zones. Outside city limits, 60 km/h and 80 km/h are frequent speed limits for roads where cyclists can be encountered. Table 4.6 shows the share of fatalities in these speed zones is respectively 7.7% and 13.2%. Although some numbers are present for speed limits of 100 km/h and over, these are exceptions, as vehicles are not to be exposed to cyclists at these speeds.

[5] In total, 2,288 bicycle accidents happened at roundabouts from 2015-2018. 1,980 of those accidents happened at 3,650 roundabouts, which is 89% of all roundabouts within city limits. In 2015-2018, that means there were at most 2,288-1,980 = 308 accidents at other roundabouts. In total, there are 1,482 roundabouts outside city limits. Per roundabout, this means there were at most 308/1,482 $\approx$ 0.21 bicycle accidents from 2015-2018. (This is the case if no accidents happened at the remaining 11% of roundabouts within city limits.)

Table 4.6: Number of fatal and serious injuries divided over speed limits (data: BRON 2010-2019)

Speed limit	Fatalities	Serious injuries	Total	% fatalities
15	0	54	54	0%
30	68	4.246	4.314	1.6%
50	326	13.605	13.931	2.3%
60	94	1122	1.216	7.7%
70	12	111	123	9.8%
80	130	858	988	13.2%
100+	5	4	9	55.5%
Unknown	20	1.032	1.052	1.9%
Total	655	21.032	21.687	3.0%

Similar to Table 4.3, the number of fatal and serious injuries is distinguished per type of infrastructure. As can be seen, the majority of accidents take place at intersections, of which the most at 4-legged intersections. Unfortunately, no distinction is made in the dataset between signalized, priority, and non-priority intersections. Another interesting finding is that although quite some accidents happen at roundabouts, only a few result in a fatality. The reduced speed of vehicles when in the proximity of a roundabout certainly ensures reduced severity of accidents, due to a lower impact speed.

Table 4.7: Number of fatal and serious injuries per type of infrastructure (data: BRON 2010-2019)

Type of infrastructure	Fatalities	Serious injuries	Total
Straight road section	185	4.936	5.121
Curved road section	13	570	583
Intersection (3-legged)	177	4.535	4.712
Intersection (4-legged)	245	7.954	8.199
Roundabout	26	2.664	2.690
Other	9	373	382
Total	655	21.032	21.687

4.2 Surrogate Measures of Safety

As SAE-level 4 Automated Vehicles are not permitted on Dutch roads, it is not possible to determine road safety between AVs and cyclists by looking at accidents. Therefore, a list of Surrogate Measures of Safety is composed, all influencing road safety between AVs and cyclists. In literature, Surrogate Measures of Safety are sometimes referred to as Safety Performance Indicators: "*indicators for risk factors that exhibit a strong causal relationship with road safety*" (Dijkstra et al., 2015, p. 5). Therefore, when referring to literature, the term Safety Performance Indicator or indicator is sometimes used. First, Surrogate Measures of Safety currently used for assessing cyclist safety are discussed. The most interesting are taken into account for the remainder of this study. Second, additional Surrogate Measures of Safety related to the performance of AVs are added.

4.2.1 Surrogate Measures of Safety for Bicycle Traffic

Surrogate Measures of Safety are searched for in scientific literature and publications by Dutch organizations focusing on cyclist safety. Multiple factors influencing bicycle traffic safety are discussed. All factors discussed belong to the source mentioned in the header of each paragraph.

Scientific Literature First of all, Chin & Quek (1997) state that an accident cannot be attributed to a single cause, and always involves the driver, his vehicle, and the road environment. Furthermore, Chin & Quek (1997) argue that safety evaluation solely based on accident numbers is difficult, due to the low rate of occurrence when accidents are segregated by locations, time, and type. This highlights the usefulness of using Surrogate Measures of Safety to assess safety. To model cycling safety, Rossetti et al. (2018) use five variables. First, the type of cycling infrastructure is taken into account, divided in five attributes: no cycling infrastructure, a bicycle lane (separated by a line, a painted surface or physical barriers), and a bicycle path. Other variables used are the width of the cycling infrastructure, traffic speed, travel time, and presence of public transport buses. Some indicators affecting road safety mentioned by Hydén (1987, in

Saunier & Sayed (2008)) are speed, the proximity of vehicles, and environmental conditions (e.g. visibility or wet road surface).

CROW - Design Manual for Bicycle Traffic (CROW, 2016) According to CROW, there are multiple requirements for bicycle traffic safety on a network level. First of all, conflicts with crossing traffic need to be avoided where possible, as each junction is a possible conflict. In particular junctions with high vehicle volumes must be prevented where possible.

Speed is another important Surrogate Measure of Safety, as a higher vehicle speed leads to an increased fatality chance in case of an accident (Figure 4.1). Therefore, it is advised to segregate cyclists and motor vehicles in case of large speed differences. At collector roads with a speed limit of 80 km/h, it is a hard requirement to segregate bicycle traffic from motor vehicles. At access roads with a speed limit of 60 km/h, mixed traffic is possible. However, this is in terms of safety and comfort not ideal for cyclists. In this case, CROW states mixed traffic can only occur at low vehicle traffic volumes, a driving speed corresponding to the speed limit, and low cyclist volumes. At intersections where bicycle traffic crosses with motor vehicles, vehicle speed must be reduced to decrease speed differences.

Uniformity in traffic situations is also mentioned as a requirement for bicycle traffic safety. Uniformity in situations can be increased by applying similar solutions per type of road infrastructure. For example, guidelines by CROW are that cyclists have no priority at roundabouts outside city limits, where cyclists have priority at roundabouts within city limits. This is closely related to recognizability. Every type of road infrastructure needs to be recognizable, such that it is predictable how the infrastructure should be used, and which behavior can be expected from all different road users. According to CROW, recognizability and uniformity are more important in situations with higher speed limits.

Another aspect mentioned is road width: CROW advises a minimum width of 1.70m for cycle lanes, to give sufficient space to cyclists. If the total road width is less than 5.80m, cycle lanes are not advised at all.

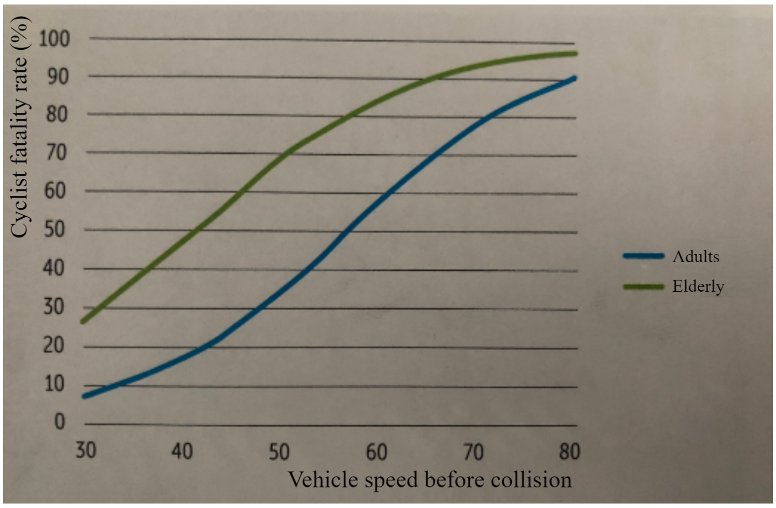


Figure 4.1: Cyclist fatality rate after colliding with a passenger car (CROW, 2016)

SWOV - Monitoring Cyclist Safety (Wijlhuizen & Aarts, 2014) In addition to traffic accident data, SWOV identified Safety Performance Indicators for cyclist safety, to better monitor this cyclist safety. A distinction is made between Safety Performance Indicators for junctions and road sections. For junctions, the number of intersections per kilometer cycled is given as an indicator, as each intersection is a potential conflict location. If possible, a distinction can be made based on characteristics that distinguish dangerous and less dangerous junctions. Characteristics mentioned are for example junction type (e.g. three-legged or four-legged intersection), junction design (e.g. one-way or two-way bicycle path), traffic volumes, and visibility. Another indicator for junctions is the speed difference between road users. For road sections, the speed difference between road users is also mentioned as an important Safety Performance Indicator. Furthermore, the degree of segregation is discussed, as separating cyclist and vehicle traffic is seen as an effective measure to increase cyclist safety. Multiple possibilities with different safety levels are given: separated bicycle paths (one-way or two-way), (advisory) bicycle lanes, bicycle streets, and no dedicated space for cyclists. Characteristics influencing safety are the width of the road surface for bicycles and the distance from a bicycle path to the carriageway.

SWOV - Safe Cycling Network (Wijlhuizen et al., 2014) In 2014, SWOV developed a system to assess the safety of cycling infrastructure. Some indicators are similar to the ones mentioned by Wijlhuizen & Aarts (2014), but are discussed in more detail. Although a relative safety level is not given, five different intersection types mentioned are junctions without priorities, right-of-way junctions, signalized intersections, roundabouts, and cycle crossings. Regarding the degree of segregation, a division is made between regular bicycle lanes and advisory (or suggested) bicycle lanes, as these have a different legal status. Traffic volume is defined as the number of vehicles (including bicycles) per hour in morning hour rush traffic.

Other indicators mentioned are among others cycling direction (one-way or two-way), the speed limit of the carriageway, and presence of street lighting.

Dutch Cyclists' Union - Safety Performance Index (Hendriksen & Kamminga, 2019) Because locations with multiple bicycle accidents in the past are getting improved in terms of traffic safety, it is getting more and more difficult to determine if there are other locations that need adjustments. Therefore, the Dutch Cyclists' Union composed a Safety Performance Index to assess bicycle safety. A total of seventeen risk factors are identified: both for single bicycle accidents and BMV accidents. The most important factors related to BMV accidents are mentioned here. Several factors are already discussed earlier, such as speed limit (higher speed causes unsafety), presence of street lighting (no or bad street lighting reduces visibility), and type of road.

The risk factor of intersections is defined as the length of the road section: shorter road sections indicate the presence of more intersections and thus more conflict situations. Two factors are related to traffic volumes. First, an increase in other traffic (both cyclists and other road users) increases the possibility of an accident. Second, a small increase in safety is mentioned as a result of Safety in Numbers. The traffic volume is assumed sufficient for this phenomenon to occur if the bicycle path is part of a main cycle route.

SWOV - Sustainable Safety (SWOV, 2018) Several of the mentioned Surrogate Measures of Safety are also discussed in the Sustainable Safety vision for 2018-2030. Exposure of vulnerable road users to motorized traffic with large differences in speed should be avoided. It is stated that motorized traffic should be limited to a maximum speed of 30 km/h to prevent accidents with serious injuries. With vehicle speeds of 50 km/h, there should be no conflicts with vulnerable road users, except with helmet-protected riders of motorized two-wheelers. Several measures are advised to slow down motorized traffic. Intelligent Speed Adaptation (ISA) will eliminate high speeds by limiting the speed of all motorized traffic. Furthermore, credible road design will slow down vehicles. Examples of credible road design are physical speed reduction measures, an uneven road surface, and a narrow cross-sectional profile.

Next to small speed differences, a low traffic volume is important for safe mixed traffic operations. Otherwise, physical segregation to separate vulnerable road users is advised. Furthermore, uniformity in infrastructure designs is mentioned as important for a sustainable safe road traffic system.

4.2.2 Surrogate Measures of Safety for Automated Vehicles and Cyclists

As shown in Section 4.2.1, many Surrogate Measures of Safety for bicycle traffic are found to be interesting, especially the ones used by Dutch organizations focusing on cyclist safety. Although all indicators mentioned are relevant for the interaction between AVs and cyclists as they are found to affect safety, they are not evenly important. This section describes how the indicators mentioned can be related to a situation where AVs and cyclists interact with each other. In such a situation, currently used Surrogate Measures of Safety will not suffice to assess road safety, as the interaction is different. Therefore, other Surrogate Measures of Safety are included, related to the characteristics and challenges of AVs. Ultimately, this leads to a final list of Surrogate Measures of Safety that are used in the remainder of this study.

Degree of segregation Although not always possible, the best way to prevent conflicts is to fully segregate cyclists from vehicles at all times. This would also be the best option for AVs, as they do not have to take into account cyclists.

Complete segregation is even more desirable for AVs, as the interaction with VRUs is seen as one of the most challenging tasks (Mannion, 2019). At junctions, complete segregation can only be realized with a grade-separated intersection, either a bridge or tunnel, which is a costly option. Therefore, it is unrealistic to change all conflict situations situated in a desired Operational Design Domain (ODD) to grade-separated intersections. Furthermore, the type of junction is mentioned as an indicator for current cyclist safety. However, as it is not yet known how AVs will behave at intersections, it is not possible to assess safety based on junction type. Therefore, other Surrogate Measures of Safety will need to be used to determine safety at junctions, such as speed and traffic volumes. At road sections, segregation of cyclists is easier. There are multiple options with different safety levels, such as physically, visually, or not segregated (Rossetti et al., 2018). It is expected that certain types of segregation are easier dealt with by AVs. Therefore, the degree of segregation will be used as a Surrogate Measure of Safety.

Vehicle speed Speed limit or speed difference of road users is often mentioned as Surrogate Measure of Safety. Although the speed limit is mentioned most often, the speed difference is considered to be more interesting. The speed difference of road users is dependent on speed limits, but also on the actual speed vehicles drive. This can be higher or lower than the speed limit, thereby directly affecting cyclist fatality rate in case of an accident (Figure 4.1). A roundabout is for example often located on roads with a speed limit of 80 km/h, but the actual speed on conflicting points with cyclists is approximately 30-40 km/h (Šurdonja et al., 2018). Sustainable Safety SWOV (2018) advocates to avoid exposure of VRUs to motorized traffic with large speed differences. Only at speeds of 30 km/h, it is advised to expose VRUs to motorized traffic. Otherwise, vehicle speed needs to be slowed down to avoid large speed differences. A lower ego vehicle speed is furthermore expected to increase environment perception of AVs. As speed difference is difficult to determine precisely as it is among others also dependent on cyclist type, vehicle speed will be used as Surrogate Measure of Safety. It is important to note that a higher vehicle speed is not affecting cyclist safety when cyclists are fully segregated from AVs, but it is in all other situations.

Cyclist traffic volume Traffic volume, often referred to as intensities, is also currently used as Surrogate Measure of Safety. To determine cyclist safety, the traffic volume of both vehicles and cyclist is taken into account, as an increase in both intensities increases exposure and thus accident chance. However, from the perspective of AVs, it is less relevant to take into account vehicle traffic volume. More other vehicles affect cyclist safety due to increased exposure, but is not directly related to unsafety caused by the AV. With larger vehicle traffic volume, indirect unsafe situations might arise. For example, red-light running of cyclists is found to increase with long waiting times at signalized intersections (Kennisnetwerk SPV, 2019). However, this is an indirect relation and is thus not primarily relevant. Vehicle traffic volume will also be of more importance with high penetration rates of AVs, although the focus of this study is mixed traffic operations with AVs and HDVs (Human Driven Vehicles). Therefore, only cyclist traffic volumes will be included as Surrogate Measure of Safety, as higher cyclist traffic volume causes AVs to encounter more cyclists. Whereas Safety in Numbers is found to increase cyclist safety (Buehler & Pucher, 2020), this is expected to have minor effects when interacting with AVs, due to their continuously scanning of the environment. Large cyclist volumes can be a larger problem for AVs compared to HDVs, as more conservative settings can lead to a decrease in vehicle traffic flow, as smaller gaps are not accepted.

Predictability of behavior A Surrogate Measure of Safety that is even more relevant for AVs, is uniformity in traffic situations, also referred to as homogeneity. This is also discussed in Hypothesis 10, expecting that better uniformity in infrastructure ensures people better behave accordingly to what is expected by other road users based on the context. Homogeneous situations thus mean certain behavior of other road users is to be expected. Clear priority rules are an example that leads to behavior that is to be expected. However, with AVs, this yielding behavior can differ based on e.g. cyclists' trust or behavior adaptation (as discussed in Section 3.2.5). This expected behavior is important for AVs to accurately predict cyclist intentions. It is even expected to be more important than for HDVs, as it is difficult for AVs to deviate from standard situations, such as informal behavior (Hypothesis 2). Instead of only uniformity leading to predictable behavior, multiple determinants mentioned need to be taken into account to assess bicyclist safety. Therefore, the Surrogate Measure of Safety that will be used is the predictability of behavior, taking into account a broader perspective towards (un)predictable behavior.

Visibility Although not found to be used as a separate Surrogate Measure of Safety, the ability to clearly oversee a situation affects cyclist safety. A situation that can clearly be overseen ensures better cyclist visibility. Wijlhuizen & Aarts (2014) state limited visibility enlarges the chance of accidents with crossing cyclists. Additionally, Andriesse & van Gurp (2020) mention early and mutual visibility for vehicles and cyclists as two important design considerations for bicycle crossings. For AVs, a clear overview is even more important than for human drivers, as (partly) occluded objects are challenging for detection (Mannion, 2019). Especially when partly occluded, human drivers are better able to detect cyclists. For assessing safety between AVs and cyclists, the ability to clearly oversee a situation is thus an important Surrogate Measure of Safety. This is defined as visibility: the extent to which a situation can clearly be overseen. If this is not the case, and the cyclist trajectory path is (partly) occluded, cyclist detection accuracy deteriorates.

Infrastructure clarity A Surrogate Measure of Safety that will be of more importance for AVs than HDVs, is clarity of the infrastructure. As discussed in Hypothesis 11, clear infrastructure ensures better understandability of AVs, which can be achieved in two ways. First, the quality of linings, such as lane markings and crossings, need to be sufficient to be properly detected by an AV. Second, the designs of this road infrastructure needs to be known by an AV to be understood. To not confuse the algorithm of the AV, it is important that this design is according to the guidelines, and that an AV is properly trained in this situation. This infrastructure clarity is important for environmental perception and thus good functioning of AVs. For Lane Assistance Systems, it is e.g. also suggested to improve the quality and uniformity of lane markings as an Operational Design Domain (ODD) requirement to improve performance (Reddy et al., 2020). Although related to homogeneity and thus predictability of behavior, this Surrogate Measure of Safety is based more on the driving performance of AVs.

Visual communication required Another Surrogate Measure of Safety specifically important for AVs is based on visual communication. Cyclists communicate their intentions by using formal and informal signs, as discussed in Section 3.5. This visual communication, such as using arm signals and making eye-contact, is suggested as one of the reasons for the low accident rate of cyclists (Walker, 2005). By visually communicating intentions, Situation Awareness for other road users is increased, enhancing safety. However, detection of VRU Vulnerable Road User gestures is mentioned as one of the challenges of AVs (Mannion, 2019). When visual communication is thus required to pass a conflict situation, AVs might not be able to do this in a safe way. Cyclists also often use visual communication when behaving informally (Hypothesis 2), which is a difficult situation for AVs. Visual communication between vehicles and cyclists is not possible at high speeds, making it in particular problematic at low speeds.

Cyclist detection accuracy Finally, cyclist detection accuracy of AVs is an important Surrogate Measure of Safety for a safe interaction with cyclists. If cyclists are not accurately detected and classified, Situation Awareness of AVs is inaccurate. Incorrect Situation Awareness can lead to dangerous situations, as shown by the crash in Arizona with an Uber test vehicle and a pedestrian (NTSB, 2018). As discussed in Section 3.2.5, cyclist detection is not yet sufficiently accurate according to literature. However, it is expected that technology will improve, eventually leading to better cyclist detection than human drivers. Especially in adverse weather conditions or during darkness, human drivers have difficulty detecting cyclists due to poor visibility (Section 3.5). The use of sensor fusion increases cyclist detection in these conditions (Section 3.2.5). During darkness, the presence of street lighting is mentioned by Wijlhuizen & Aarts (2014) and Wijlhuizen et al. (2014) to positively affect cyclist safety due to increased visibility. For AVs, no information on the influences of street lighting on cyclist detection accuracy is found. Cyclist detection accuracy is also related to visibility, however, this Surrogate Measure of Safety is focused more on detection and classification capabilities in general.

4.2.3 Final List of Surrogate Measures of Safety

As described in Sections 4.2.1 and 4.2.2, the most interesting Surrogate Measures of Safety found to assess safety of conflict situations between AVs and cyclists, are as follows:

- *Degree of segregation* - The way in which cyclists are segregated from vehicles
- *Vehicle speed* - The speed that an AV drives at a conflict situation
- *Cyclist traffic volume* - The number of cyclists per hour at the busiest time of day

- *Predictability of behavior* - The extent to which the conflict situation facilitates predictable cyclist behavior
- *Visibility* - The extent to which the conflict situation can clearly be overseen
- *Infrastructure clarity* - The extent to which the infrastructure is clear and recognizable
- *Visual communication required* - The extent to which visual communication is needed to achieve a safe interaction
- *Cyclist detection accuracy* - The ability of an AV to accurately detect and classify cyclists

4.3 Potential Conflict Situations for Automated Vehicles and Cyclists

All infrastructure situations where cyclists can be encountered can be seen as a potential conflict situation. However, this is not always problematic, as exposure does not automatically lead to accidents. The relation between exposure and accidents is shown in Figure 4.2. Amundsen & Hyden (1977, in Chin & Quek (1997)) consider accidents to be a subset of serious conflicts, which is a subset of all conflicts, caused by exposure. The widely used definition of a conflict is as follows: *"an observational situation in which two or more road users approach each other in space and time to such an extent that a collision is imminent if their movements remain unchanged"* (Amundsen & Hyden (1977) in Saunier et al. (2010, p. 42)). A conflict is thus not necessarily a problem, as either the AV or vehicle can change their movement by either decelerating or changing directions. If there is a serious conflict, such as a near-miss, an accident could only just be avoided. A serious conflict thus indicates a larger problem, as another similar scenario could result in an accident. Therefore, these serious conflicts should be avoided, and the situations potentially leading to these conflicts should be considered: referred to as potential conflict situations.

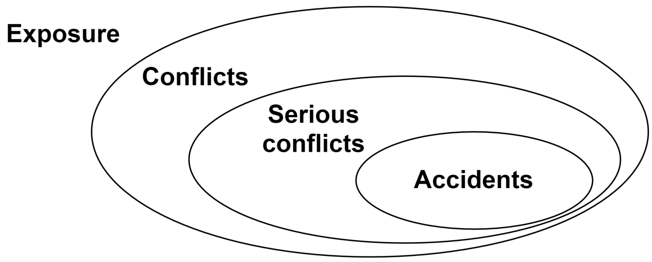


Figure 4.2: Set representation showing the relation between exposure, conflicts and accidents (redrawed based on Amundsen & Hyden (1977) as shown in Chin & Quek (1997, p. 172))

As AVs are not yet interacting with cyclists, accident data is not available to highlight dangerous situations. Therefore, it cannot be said with complete certainty whether a situation is dangerous or not for the interaction between AVs and cyclists. However, based on the identified determinants, BMV-accident details, and Surrogate Measures of Safety, some potential conflict situations can be identified. As explained in the scope of this research (Section 1.2), the focus is on Dutch road infrastructure situations outside city limits.

Signalized intersections As presented in Table 4.4, relatively many serious injury accidents happen at signalized intersections. Therefore, it is certainly an interesting situation to take into account as a potential conflict situation. Red-light running, both consciously and unconsciously, is currently one of the main risk factors at signalized intersections (Kennisnetwerk SPV, 2019). As AVs are not distracted and can communicate with traffic lights, it is expected that red-light running will diminish. However, the risk of red-light running of cyclists remains.

A special type of signalized intersections is when a permitted conflict is present. Not giving priority at permitted conflicts is indicated to be one of the most common accident types at signalized intersections (Kennisnetwerk SPV, 2019). For AVs, it can be confusing that they need to yield for cyclists while having a green light. At the roads managed by the Provincie Noord-Holland, there are in total 22 signalized intersections with a permitted conflict, of which eight involving cyclists. All eight permitted conflicts are when exiting a provincial road.

Priority intersections Another type of infrastructure that is currently overrepresented in BMV accident locations is priority intersections. There are two common potential conflict situations at priority intersections: cross traffic (a cyclist crossing a main road) or through traffic (a cyclist driving along a main road and crossing a side street). Both situations are interesting to take into account for the interaction between AVs and cyclists. The inattention of road users is a frequent accident cause at these intersections (Reurings et al., 2012), which is expected to improve with AVs present. Cyclists taking right of way while having to yield, the other frequent accident cause, is still a risk factor.

As non-priority intersections are mostly located within city limits, these are not taken into account as a potential conflict situation in this study.

Roundabouts Although roundabouts are currently relatively safe in terms of the number of BMV accidents, it is questionable if this is the same for a scenario with AVs. Visual communication between cyclists and human drivers is often present at the situations to communicate intentions, thereby increasing safety. Furthermore, informal or violating behavior of cyclists is easily possible, among others due to low vehicle speeds. These scenarios are expected to be more challenging for AVs than for human drivers.

Two different types of roundabouts are distinguished: cyclists having priority or not. Outside city limits, cyclists do not have priority at the majority of roundabouts. However, as it is interesting to explore the differences in safety for both priority rules, both roundabout situations are taken into account for the remainder of this study.

Access roads Many access roads are present outside city limits, where the road is shared with all types of road users. Access roads have many risk factors, such as large speed differences and no segregation. However, fewer accidents happen than what can be expected based on the risk factors, among others due to low traffic volumes. If cyclist volumes are larger, a separate cyclist path is often provided (CROW, 2016). Still, many risk factors are present that are challenging for AVs.

In general, access roads can be divided in two different types: with or without advisory bicycle lanes. The presence of advisory bicycle lanes is often based on the width of the road (CROW, 2016). To explore the differences in safety of both infrastructure types, both situations are taken into account.

Bicycle lanes Although primarily occurring in city centers, visual segregation in terms of a bicycle lane is an interesting situation to take into account. As bicycle lanes are by design wider than advisory bicycle lanes, more space for cyclists is provided. As discussed in Section 3.9, there are two types of bicycle lanes with different legal statuses: marked with a solid or a broken line. In case of a solid lane, vehicles are never allowed to drive on the bicycle lane. The segregation between vehicles and cyclists is stricter, and therefore more interesting for a situation with AVs than a bicycle lane with a broken line. Compared to an access road with an advisory bicycle lane, the space for cyclists is clearer. Therefore, this situation is expected to score better on infrastructure clarity. However, AVs are still only visually segregated from cyclists, which is a risk factor.

4.4 Conclusions

Certain results of this chapter will be used as input for the remainder of this study. The analysis of current bicycle-motor vehicle accidents shows the majority of cyclist accidents took place within city limits, emphasizing the complex cycling environment in urban areas. An important finding for accidents outside city limits is the large share of cyclist fatalities resulting from accidents. An increase in vehicle speed was found to increase accident severity. This vehicle speed is among others taken as a Surrogate Measure of Safety to assess road safety. An overview of all eight Surrogate Measures of Safety identified to objectify road safety between AVs and cyclists is provided in Table 4.8.

Table 4.8: Overview of Surrogate Measures of Safety to objectify road safety between AVs and cyclists

Surrogate Measure of Safety	**Definition**
Degree of segregation	The way in which cyclists are segregated from vehicles
Vehicle speed	The speed that an AV drives at a conflict situation
Cyclist traffic volume	The number of cyclists per hour at the busiest time of day
Predictability of behavior	The extent to which the conflict situation facilitates predictable cyclist behavior
Visibility	The extent to which the conflict situation can clearly be overseen
Infrastructure clarity	The extent to which the infrastructure is clear and recognizable
Visual communication required	The extent to which visual communication is needed to achieve a safe interaction
Cyclist detection accuracy	The ability of an AV to accurately detect and classify cyclists

Based on the current bicycle-motor vehicle accident details and identified Surrogate Measures of Safety, potential conflict situations for interaction between AVs and cyclists are identified. A list of these potential conflict situations, focused on situations outside city limits, is as follows:

- Signalized intersections (regular or with a permitted conflict)
- Priority intersections (conflict with cross traffic or through traffic)
- Roundabouts (cyclists having priority or cyclists having no priority)
- Access roads (regular or with advisory bicycle lanes)
- Bicycle lanes

Highlights

- Current bicycle-motor vehicle accident details highlight the large share of cyclist fatalities in case of accidents outside city limits, mainly caused by vehicle speed
- A list of Surrogate Measures of Safety is presented that can be used objectify road safety between AVs and cyclist (Table 4.8)
- Several potential conflict situations outside city limits are presented that will be used as input for the expert interviews

5 Expert Interviews

This chapter presents the results of the expert interviews. First, background information of the experts interviewed is presented in Section 5.1. To clarify the context of how information is obtained from the experts, the interview structure is elaborately explained in Section 5.2. Afterward, the interview results are discussed in Section 5.3, divided into quantitative and qualitative results. The most important results are presented in Section 5.4. An overview of the slides used for the expert interviews is included in Appendix B.

5.1 Overview of Experts

An overview of background information on the interviewed experts is given in Table 5.1. To obtain a diverse range of opinions, experts were selected from different backgrounds: academic research parties, governmental bodies, and from the cyclist industry. Two experts of the TU Delft were interviewed, however, they work both at a different faculty. The expert ID is based on the chronological sequence of interviews. For one expert (ID 8), the interview slides were sent in advance. Table 5.1 includes self-reported cycling frequency and Automated Vehicle (AV) familiarity. All experts were frequent cyclists, with most of the experts cycling on a daily basis. An important note is that cycling frequency is based on the situation before the COVID-19 pandemic. Regarding AV familiarity, almost all experts from academic research parties and governmental bodies stated they are very familiar with AVs. Interviewed experts from the cyclist industry stated to be familiar or fairly familiar with AVs, indicating that all experts have experience with AVs.

Table 5.1: Background of experts interviewed, including self-reported cycling frequency and AV knowledge

	Expert ID	**Company**	**Cycling frequency**	**AV familiarity***
Academic Research Parties	Expert 3	TU Delft	Daily (6-7x per week)	Very familiar
	Expert 5	TU Delft	Daily (6-7x per week)	Very familiar
	Expert 9	SWOV	2-5x per week	Very familiar
Governmental Bodies	Expert 1	Provincie Noord-Holland	Daily (6-7x per week)	Fairly familiar
	Expert 4	CROW	Daily (6-7x per week)	Very familiar
	Expert 7	European Commission	Daily (6-7x per week)	Very familiar
	Expert 10	Dutch Vehicle Authority (RDW)	Daily (6-7x per week)	Very familiar
Cyclist Industry	Expert 2	Goudappel Coffeng	Daily (6-7x per week)	Fairly familiar
	Expert 6	Dutch Cyclists' Union	Daily (6-7x per week)	Familiar
	Expert 8	CROW Fietsberaad	2-5x per week	Fairly familiar
	Expert 11	Dutch Cycling Embassy	Daily (6-7x per week)	Familiar

**Experts were asked about their familiarity with AVs, on a 5-point scale: Not familiar / Somewhat familiar / Fairly familiar / Familiar / Very familiar*

5.2 Structure of Interviews

The structure of the interview was identical for each expert and consisted out of five parts.

The first part contains a short introduction to the present study, including the definition of Automated Vehicles that is referred to. It is made clear that the focus of this study is on cyclist traffic safety in typical Dutch situations. Furthermore, three assumptions were given about Automated Vehicles:

- SAE-level 4, which is highly automated and fully self-driving within a limited domain (Operational Design Domain)
- There is always a human driver present in the vehicle to take over outside the Operational Design Domain (ODD)
- If there is an unknown situation, the human driver will take over. If the human driver does not take over, the AV will bring itself in a minimal risk condition

After the short introduction, the experts were asked if they had any remaining questions before proceeding.

The second part consists of three background questions to gather some information about the experts on a 5-point scale. First, their cycling frequency was asked. Second, their familiarity with Automated Vehicles was questioned. The third question was about their trust in the technology of Automated Vehicles, where they were invited to elaborate on their score.

In the third part, the potential conflict situations were presented. A total of nine different situations (Table 5.2) are discussed in the interviews, as determined in Section 4.3. A clear image of each situation was searched for via Google Streetview. Images of each specific situation are shown in Figure 5.1. Enlarged images of each situation are presented in Appendix B.

Table 5.2: Type of infrastructure situations discussed

Situation	**Type of infrastructure**
Situation 1	Signalized intersection
Situation 2	Signalized intersection (permitted conflict)
Situation 3	Priority intersection (cross traffic)
Situation 4	Priority intersection (through traffic)
Situation 5	Roundabout (cyclists having no priority)
Situation 6	Roundabout (cyclists having priority)
Situation 7	Access road
Situation 8	Access road (with advisory bicycle lanes)
Situation 9	Bicycle lane

For each situation, the same three questions were asked. First, the level of complexity for AVs was questioned, focusing on a scenario where AVs and cyclists are interacting. The level of complexity was scored on a 5-point Likert scale. A score of 1 corresponded with low complexity, meaning that cyclist safety was expected to increase with the presence of AVs. A score of 5 corresponded with high complexity, meaning that cyclist safety was expected to decrease with the presence of AVs. A score of 3 was presented as neutral, meaning cyclist safety was not expected to change. Second, the reasoning behind the given score was questioned as an open question. Sometimes, follow-up questions were asked to get an additional explanation for a reason or to obtain more arguments. Finally, the experts were asked whether they would include the situation in the initial Operational Design Domain of AVs if they were to drive on Dutch roads. Before going through the nine situations, a test situation was presented to see if the questions were clear. A cycle street with multiple risk factors was selected as the test situation, to invite experts to mention some challenges.

After all nine situations were discussed, the fourth part consists of a ranking of the safest and unsafest situations. A list of situations is presented, and experts were asked to give a top-3 of situations that they considered to be the safest and unsafest. Again, here it is emphasized that the focus is on traffic safety for cyclists.

Finally, in the fifth part, there was room for additional questions or remarks from the experts.

5.3 Interview Results

This section describes the results of the interviews. First, some more generic quantitative results will be presented. Afterward, the qualitative results will be discussed, both per specific situation as per Surrogate Measure of Safety.

5.3.1 Quantitative Interview Results

This section describes the quantitative results of the interviews. An overview of the quantitative interview data is included in Appendix C.

Figure 5.2 shows the complexity scores of each situation, given by the experts. As described in Section 5.2, the given scores range from 1 to 5. A score of 1 is not complex and cyclist safety is expected to increase with AVs present, whereas a score of 5 means it is too complex for AVs, and cyclist safety is expected to decrease with AVs. A score of 3 is neutral, which corresponds with expectations similar to HDVs (Human Driven Vehicles). The reasoning behind the given scores is discussed in Sections 5.3.2 and 5.3.3. As can be seen in Figure 5.2, all experts expect cyclist safety to increase at signalized intersections (situation 1). The experts are less optimistic when a permitted conflict is present (situation 2), but the given scores are still mostly positive. When looking at the priority intersections, the situation with cross traffic (situation 3) is evaluated significantly more complex than with through traffic (situation 4). In the latter situation, the majority of experts expect cyclist safety to improve, given the number of complexity scores of 2. However, there are also some experts that think bicycle safety will be decreased. Regarding the roundabouts, cyclists having priority (situation

Situation 1

Situation 2

Situation 3

Situation 4

Situation 5

Situation 6

Situation 7

Situation 8

Situation 9

Figure 5.1: Overview of images representing the type of infrastructure situations (enlarged images are presented in Appendix B)

6) is on average evaluated less complex than cyclists having no priority (situation 5). However, the given scores are very diverse, as some experts indicated that cyclist safety will decrease. Given the number of times a maximum complexity score of 5 is given, it is clear that access roads are considered the most complex by the experts. This is especially the case without advisory bicycle lanes (situation 7), where seven experts expect cyclist safety to decrease with AVs present. For the situation with advisory bicycle lanes (situation 8), it is also expected by most experts that safety will decrease due to complexity. The final situation, with bicycle lanes, is evaluated diverse, although no expert has given the maximum complexity score.

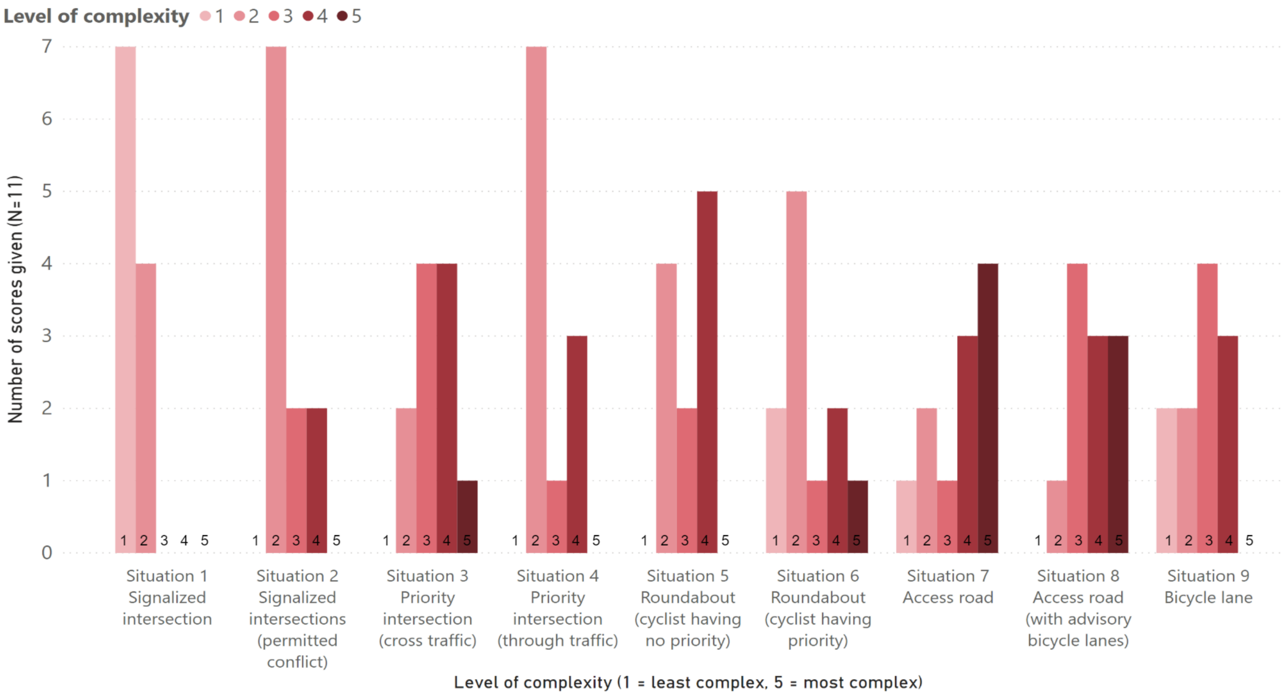


Figure 5.2: Complexity scores per infrastructure situation

Next to the complexity scores, the experts were asked if they would include each situation in the Operational Design Domain (ODD) if AVs were to be permitted on the roads. The results for each situation are displayed in Figure 5.3. It has to be noted that this does not mean an expert would include all versions of a situation in the ODD, but it was determined for the specific representation of the situations as depicted in the interviews (as illustrated in Appendix B). Whether or not an expert would include a situation in the ODD is related to the complexity scores given in Figure 5.2, but there are some differences. For example, sometimes a situation with a neutral score is included in the ODD, and sometimes not. Based on Figure 5.3 it is not possible to directly compare all situations and draw firm conclusions, as it is also dependent on what an expert expects from an SAE-level 4 AV. Despite the given explanation, this can differ (and appeared to be different) between experts, based on their previous experience with AVs. However, Figure 5.3 gives a clear indication of which situations are considered to have more potential to be included first in the ODD, relative to other situations. For example, almost all experts would include signalized intersections (situations 1 and 2) in the ODD. This is also the case with permitted conflicts present, as experts expect an SAE-level 4 AV can deal with the situation. Situations that are considered more complex (Figure 5.2) are subsequently more often not included in the ODD, such as the priority intersection with cross traffic (situation 3) and both types of access road (situations 7 and 8). On the other hand, some experts think AVs can drive sufficiently safe in these situations. The results for the other situations are more mixed. Similar as discussed previously, regarding roundabouts experts are more optimistic when cyclists are having priority, compared to cyclists not having priority.

At the end of each interview, experts were asked to make a ranking of the three safest and unsafest situations. An overview of how often each situation is mentioned as safest is shown in Figure 5.4. Contrary to the previously discussed figures, the number of expert interviews included is ten. One expert indicated it was too difficult to make this ranking at this moment in time, as there are currently too many uncertainties regarding AVs' behavior towards cyclists. The other experts were

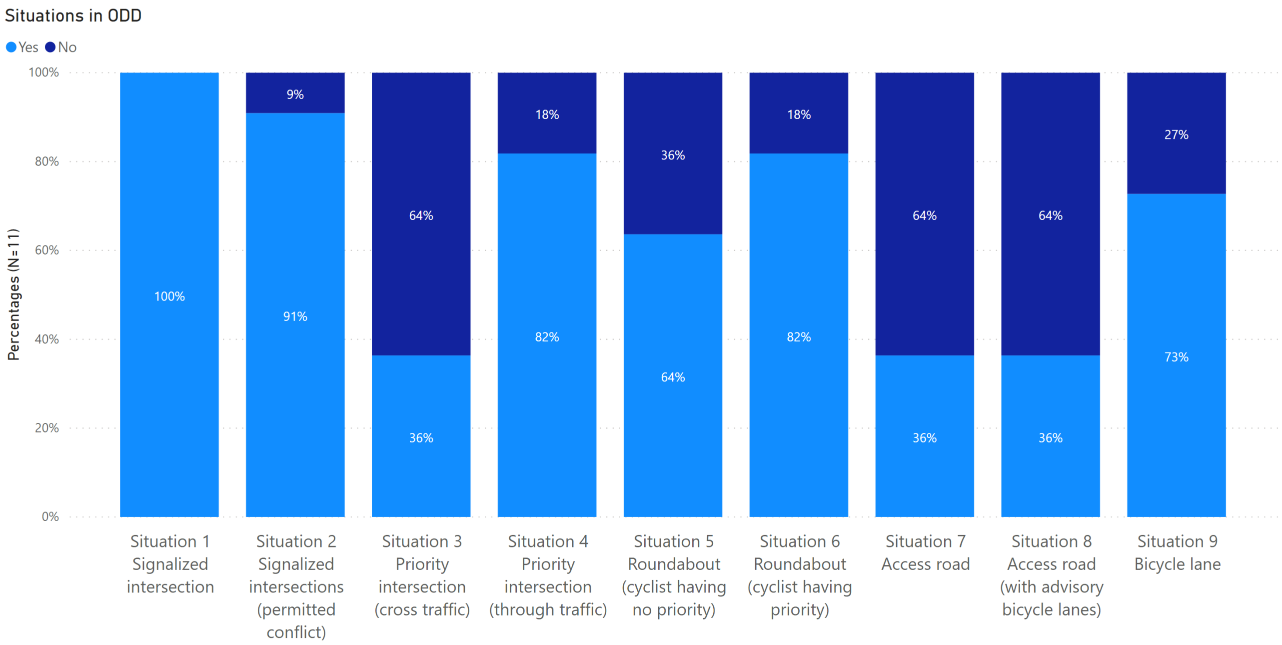


Figure 5.3: Situations to be included in the ODD or not, according to the experts

almost unanimously that a regular signalized intersection (situation 1) is the safest situation of all situations presented. The expert who evaluated the bicycle lane as the safest situation, considered the signalized intersection as the second safest option. The signalized intersection with permitted conflict (situation 2) is often mentioned as the second or third safest situation. It is notable that situation 4 (priority intersection with through traffic) is only mentioned once, when compared to the fact that nine out of eleven experts think the situation could be added to the ODD. Again, the conclusion for roundabouts is similar as before: cyclists having priority is mentioned twice as often in the ranking of safest situation, compared to cyclists having no priority. One remarkable result is that situation 7 is once mentioned as the third safest situation. The corresponding expert reasoned that this is currently also a complex situation for HDVs, and AVs are to increase safety compared to human drivers. However, based on the overall results and the fact that accidents with cyclists need to be actively avoided in the early stages of AV deployment, situation 7 is considered to be unsafe.

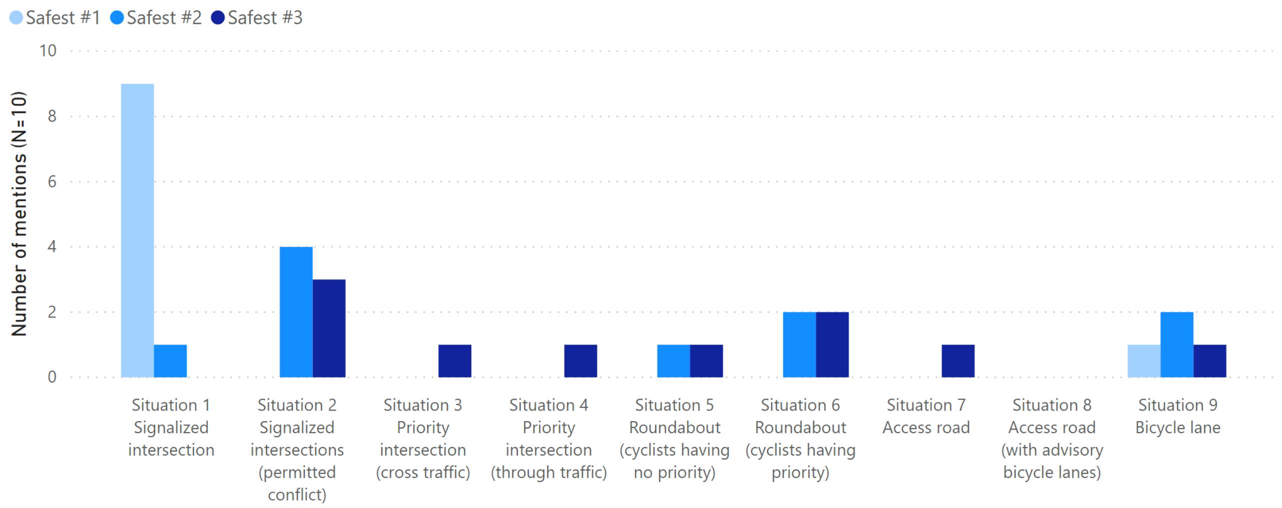


Figure 5.4: Number of times a situation is mentioned in the top-3 of safest situations

Next to the ranking of safest situations, Figure 5.5 shows how often each situation is mentioned as unsafest. Again, the number of expert interviews included is ten, as one expert indicated it was too difficult to make this ranking. As could be expected based on previously discussed results, the regular signalized intersection (situation 1) is not mentioned as the unsafest situation. The expert who mentioned situation 2 (signalized intersection with permitted conflict) also included the situation in the ODD. This shows that a mention in the ranking for unsafest situations does not always mean a situation is not evaluated as sufficiently safe. However, it does show the relative unsafety between situations. Situation 7 (access road) is most often mentioned as the unsafest situation. The access road with advisory bicycle lanes (situation 8) is most often mentioned as the second unsafest situation. Except for 1 expert, everyone who scored situation 8 as second unsafest, had situation 7 as unsafest, clearly showing that situation 8 is preferred over situation 7. Furthermore, a priority intersection with cross traffic is mentioned quite often. Regarding roundabouts, cyclists not having priority is again considered to be less safe compared to cyclists having priority. Finally, the last mentions are divided over the other situation, without remarkable appearances.

When comparing the results shown in Figures 5.4 and 5.5, almost all situations are mentioned as both unsafe and safe, by different experts. This shows the complexity of assessing the safety of a specific situation, as there are multiple reasons that influence a decision. This reasoning will be discussed in Section 5.3.2 for each situation specific.

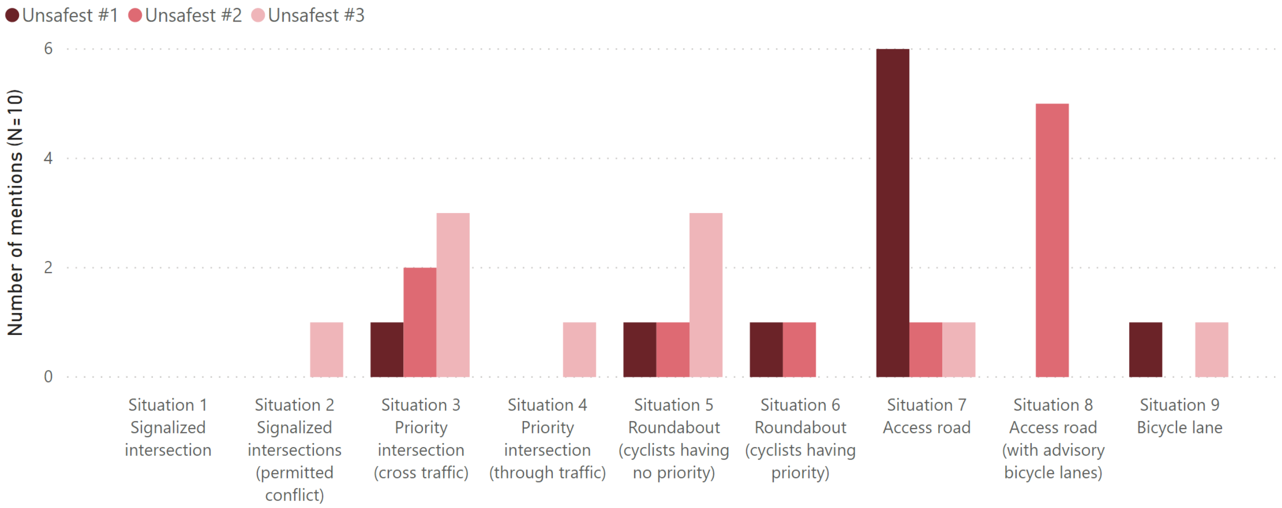


Figure 5.5: Number of times a situation is mentioned in the top-3 of unsafest situations

After giving a complexity score for each situation (Figure 5.2), experts were asked for the reasoning behind their choice. Each reason given is linked to the Surrogate Measures of Safety listed in Section 4.2.3. Not every reasoning could be directly related to the predefined Surrogate Measures of Safety. Therefore, some reasons are classified as *'other'*. Additionally, as many experts mentioned traffic violations of cyclists to affect safety, this is added as a separate Surrogate Measure of Safety: *The extent to which the conflict situation facilitates cyclist traffic violations.*

An overview of the number of times a Surrogate Measure of Safety is mentioned for each specific situation is shown in Figure 5.6. As the total number of experts is eleven, the maximum number of mentions is eleven. No division is made in the direction of mentions, whether positively or negatively affecting cyclist safety. This figure functions to give an overview of which Surrogate Measures of Safety are to be considered per situation. Sections 5.3.2 and 5.3.3 discuss the specific reasoning in more detail. If a Surrogate Measure of Safety is not mentioned by an expert, it does not mean it is not important in the situation, as interview time was limited and not every situation could be discussed in great detail. However, it indicates that it is presumably not the most important Surrogate Measure of Safety. Furthermore, it could be so evident that it is not worth mentioning. For example, the vehicle speed at situation 8 is already mentioned by multiple experts at situation 7. Most experts highlight the differences with the previous situation, instead of repeating the previous reasoning in comparable situations.

As can be seen in Figure 5.6, reasons related to the predictability of behavior are mentioned most. This is in particular for situations where cyclist behavior is better predictable, such as signalized intersections (situation 1 and 2) and roundabouts where cyclists have priority (situation 6). Cyclist traffic violations was mentioned often as a possible risk, in particular in situations where vehicles have right of way (situation 1, 3 and 5). This is logical, as cyclists having priority cannot violate the priority rules. Cyclist detection accuracy is also often mentioned, but in particular as a requirement for an AV to be permitted at a situation. It is expected by the experts that SAE-level 4 AVs are better in cyclist detection than human drivers. Visual communication required is often mentioned in combination with vehicle speed, as low vehicle speeds better facilitate visual communication. As discussed in Section 4.2.2, this visual communication is seen as a challenge for AVs.

A qualitative discussion of the reasoning is discussed in Sections 5.3.2 and 5.3.3. An overview of all reasons given by the experts, allocated per Surrogate Measure of Safety per situation, is included in Appendix C.

Surrogate Measure of Safety	1. Signalized intersection	2. Signalized intersection (permitted conflict)	3. Priority intersection (cross traffic)	4. Priority intersection (through traffic)	5. Roundabout (cyclists having no priority)	6. Roundabout (cyclists having priority)	7. Access road	8. Access road (with advisory bicycle lanes)	9. Bicycle lane	Total
Degree of segregation	4	1	2	0	0	0	5	8	8	28
Vehicle speed	3	1	6	2	5	4	7	2	2	32
Cyclist traffic volume	0	1	0	2	2	1	6	5	1	18
Predictability of behavior	10	8	5	6	7	11	3	5	6	61
Visibility	1	1	7	6	3	2	1	0	2	23
Infrastructure clarity	1	3	2	1	1	3	1	6	1	19
Visual communication required	0	0	2	1	4	2	1	1	1	12
Cyclist detection accuracy	5	9	3	8	5	5	5	2	2	44
Cyclist traffic violations	9	2	7	0	8	1	0	0	2	29
Other	5	6	4	6	3	4	7	7	0	42

Figure 5.6: Number of times a Surrogate Measure of Safety is mentioned for each specific situation (N=11)

5.3.2 Qualitative Interview Results per Situation

This section describes the qualitative results of the interviews. For each situation, the most important Surrogate Measures of Safety will be discussed, based on the experts' opinions. A more elaborate overview of expert opinions per Surrogate Measure of Safety is included in Appendix C.

Situation 1 - Signalized intersection Being fully regulated, experts considered this a non-complex situation. Because the situation is regulated by traffic lights, there should be no direct conflict situations, making the situation predictable. It is clear what is expected from an AV and what cyclist behavior an AV can expect, leading to few unexpected movements. AVs are less likely to run the red light compared to HDVs, increasing cyclist safety.

Almost all experts mentioned red-light running of cyclists as a risk in this situation. However, they expect that an AV better recognizes a cyclist running the red light compared to an HDV, among others due to human distraction and reaction time. The speed of an AV is an important factor influencing the probability of collision. Lowering the speed of an arriving AV improves the ability to correct for cyclists running the red light. Additionally, one expert mentioned the large scale of this specific intersection as a factor preventing cyclists to run the red light.

An important note is that several experts stated they assumed there will be communication between the traffic lights and the AV. This is something to take into account to increase safety in this situation.

Situation 2 - Signalized intersection (permitted conflict) Signalized intersections with a permitted conflict between right-turning vehicles and cyclists going straight are evaluated as more complex than regular signalized intersections. The main reason is that there is a possible conflict. The situation is still quite predictable, as cyclists can be expected and are always having right of way. The AV knows that it needs to give priority to cyclists and will do so, possibly lowering its speed to anticipate for cyclists.

The cyclist detection accuracy of SAE-level 4 AVs is deemed better than HDVs. With turning traffic, cyclist detection is always more difficult, but it is expected that an AV can handle this in a safe way. If it is a two-way cyclist crossing, a common human error is that only one direction is looked at (Schepers et al., 2011). The large number of sensors on an AV ensures this type of error will occur less. If it is a one-way cyclist crossing, a possible violation can be that a cyclist is coming from the wrong direction. However, it is also expected that an AV will detect these cyclists in time.

Again, communication between the traffic lights and AV is mentioned as an important assumption in this situation, to anticipate the status of the traffic light. Additionally, a traffic sign clarifying the present permitted conflict is helpful.

Another important factor is the sensitivity of the AV. When cyclist intensity is high, an AV might not accept a gap that a human driver would have accepted. This increases the safety of cyclists, but can lead to irritation or incomprehension of human drivers.

Situation 3 - Priority intersection (cross traffic) Most of the experts evaluated a priority intersection with crossing cyclists as a complex situation for AVs, based on multiple reasons. In general, unsignalized intersections are considered more difficult due to the absence of traffic lights, thereby adding unpredictable behavior. According to the law, cyclists need to stop and give way to coming vehicles. However, multiple experts mention that a crossing cyclist not respecting the right of way is a risk and will happen. With HDVs, these situations are often handled with interaction between the driver and a cyclist, to communicate their intentions. For AVs, such a form of communication is more difficult, making this a complex situation. However, if a cyclist unexpectedly crosses the road, it is assumed that AVs can react faster than HDVs, in theory.

Based on the lining on the road surface, which is meant to slow down vehicles, an AV should adjust its speed in this situation. If a cyclist unexpectedly crosses the road, driving at the maximum speed creates a dangerous situation. Decelerating ensures better detection of cyclists. However, the speed must not be too low that it deteriorates traffic flow.

For this specific situation, the clarity of the infrastructure is not ideal for AVs. It is not clear that there is a cyclist crossing, the lines at the roadside are missing, and the red color of the road suggests it is a non-priority intersection.

An important factor questioned often for this situation is whether the overview is sufficiently clear, or that there will be any occlusion caused by the bushes. Most of the experts think this is just fine, but it is important to ensure in similar situations that cyclists are not occluded and an AV can easily track their path.

One expert mentioned the importance of the distance from the cycle path to the road, which is considered sufficient in this situation. If this distance is too small, there is no place for cyclists to safely wait, and it is difficult to look for oncoming traffic while making the turn towards the crossing. This is also advised by CROW: the minimum distance from the road to the cycle path is five meters (Andriesse & van Gurp, 2020).

Situation 4 - Priority intersection (through traffic) A priority intersection with a potential conflict with through traffic is considered less complex than the previous situation with crossing traffic. The main reason given is that the situation is more predictable because cyclists have priority. Cyclists expect an AV to stop, and an AV knows they have to yield for cyclists, given the assumption that an HD-map of the situation is included in the software of the AV. Interaction between an AV and cyclists is not required in this situation, as the priority rules are clear.

Cyclists coming from two ways is mentioned as a risk, although the experts expect that AVs will detect cyclists better than human drivers. When multiple types of sensors are used (i.e. RADAR, LIDAR, and vision-based), it is also expected to better detect cyclists in adverse weather conditions. Although not in the scope of this study, an important aspect to mention is the presence of faster cyclists, such as e-bikes ($\pm$ 25 km/h) and speed-pedelecs (up to 40 km/h). Roads like this, where cyclists have priority and can travel for long distances without stopping, are attractive for these faster cyclists. The question is if an AV can also detect these cyclists in time.

Additionally, many experts mention this is a really clear situation without occlusion, which is appropriate for cyclist detection. Furthermore, the AV speed will be low, because it needs to decelerate to make a turn. This ensures more time for detection, and a small braking distance, both increasing cyclist safety.

With high cyclist intensities, it can occur that an AV has a long waiting time before being able to safely cross the cycle path. AVs will inherently be more conservative towards accepting a gap compared to HDVs. This can lead to secondary problems on the main road, as an unsafe situation is created if a vehicle is standing still on the road. However, in this specific situation, the distance between the road and the cycle path is sufficient to safely wait for cyclists to pass, without blocking the main road. To prevent unsafe situations on the main road, this distance is an important design factor in these situations, especially with AVs.

Situation 5 - Roundabout (cyclists having no priority) Experts mention some improvements that AVs will have over HDVs at roundabouts where cyclists have no priority. For a human driver, it is difficult to divide the attention between looking at other vehicles to determine if it is safe to enter the roundabout, and detecting cyclists, sometimes even from both sides. For AVs, this will be easier and cyclists will not be overlooked due to all sensors and the clear overview in this specific situation.

However, this situation is not consequently assessed as safe for the interaction between AVs and cyclists. In theory, cyclists do not have priority and need to yield for vehicles, but cyclists take priority regularly according to experts. This makes their behavior difficult to predict for AVs, and it is questionable if AVs can act adequately. When cyclists interact with HDVs, there often is visual communication in these situations to communicate intentions, both from the cyclist and from the human driver. An example is in high traffic volumes, where vehicles are waiting to enter the roundabout. Cyclists will cross in between waiting vehicles, and mostly human drivers give them the opportunity. For AVs, this social interaction is difficult.

An interesting aspect mentioned is the presence of different types of cyclists. For human drivers, it is possible to distinguish different cyclists types, who might have different intentions. For example, a racing cyclist will more often take priority compared to an approaching parent with its child. It is really questionable if an AV can make these distinctions properly.

When approaching the roundabout, the vehicle speed is low (approximately 30-40 km/h according to Šurdonja et al. (2018). This ensures good cyclist detection accuracy of the AV and a diminished chance of a fatal outcome in case of a collision. However, this low speed also encourages social interaction and thereby visual communication, which is difficult for AVs.

Situation 6 - Roundabout (cyclists having priority) Experts assess this situation as less complex compared to roundabouts where cyclists do not have priority. Almost all experts reason that cyclist behavior is very predictable because cyclists have priority. The rule for AVs is clear, as they always have to yield for cyclists. Opposed to the previous situation, there will be less visual communication, as cyclists often cross without looking at the approaching vehicle, because they expect that vehicles will yield.

The speed of vehicles approaching the roundabout will be lower than in the previous situation, because they have to give priority to both cyclists and pedestrians. For human drivers, it is difficult to pay attention to pedestrians, cyclists, and vehicles. As there is a clear overview in this situation, AVs are expected to detect all different road users accurately. It is important that AVs take into account possible cyclists coming from the wrong direction, if it is a one-way cycle lane.

When AVs need to yield for cyclists, it is important that the situation is recognizable for the system. Next to the HD-map, it is valuable if the priority rules are also displayed with a road sign and give-way road markings. One expert mentioned the poor infrastructure quality in this specific situation, as the road markings are deteriorated. Additionally, the road marking of the cycle path is not according to the guidelines, which can make it complicated for AVs what to expect.

Finally, homogeneity between roundabouts is mentioned. If there are many different types of roundabouts with different priority rules, it may not always be clear what to expect from other road users. In the Netherlands, CROW has composed guidelines for priority rules on roundabouts. However, as these are guidelines, it is possible to deviate from that. If there is homogeneity in infrastructure, the predictability of behavior is increased, ensuring safer interaction.

Situation 7 - Access road Most of the experts considered an access road as the most complex situation, mainly due to the degree of segregation and the vehicle speed. There is no physical segregation and no proper visual segregation. There are some lines at the side of the road indicating a possible cycle path, but this is way too small for cyclists and also not intended as a space for cyclists. Cyclists do not have a dedicated space, making their behavior and location on the road unpredictable. If there is an oncoming vehicle, the AV will need to deviate from its path and drive close to the roadside, where cyclists also cycle. This shared space can result in dangerous situations, especially if there are multiple cyclists.

Another factor influencing safety is speed. The speed difference between vehicles and cyclists is high and thus deemed unsafe. Without traffic calming measures, HDVs often violate the speed limit on similar roads. An advantage of AVs will be that they adhere to the speed limit, decreasing the speed difference with cyclists. However, this can lead to irritation for succeeding HDVs who might want to drive faster. Furthermore, overtaking a cyclist while driving 60 km/h will not be perceived as safe by cyclists. Although cyclist detection is easy in such a clear situation, the combination of speed and complexity of the shared space makes this a difficult situation.

Cyclist detection is easy, as this is a clear situation and not many cyclists are expected. However, if traffic volumes are higher and there are both oncoming vehicles and cyclists, there is a lot to take into account, which complicates the situation.

One expert mentioned this as a non-complex situation, however with the assumption that similar access roads are only present with low cyclists volumes. With higher traffic volumes, the expert assesses this situation as more complex and would suggest different infrastructure, such as a separate cycle path.

Situation 8 - Access road (with advisory bicycle lanes) The presence of advisory cycle lanes is evaluated to improve safety on access roads, because there is a clearer space for cyclists. Although this situation is still not perceived as safe, most of the experts prefer this situation over the previous. The different color of the advisory cycle lanes ensures better predictability of the location of both AVs and cyclists, as this infrastructure is more straightforward. However, cyclists are allowed to cycle next to the advisory cycle lane, for example when overtaking other cyclists. Then, visual communication might be needed to safely communicate their intentions. It is even allowed for other vehicles to stand still on the advisory cycle lane, which leads to cyclist behavior that is difficult to predict for an AV.

However, there are still some dangerous aspects. Similar to the previous situation, an AV needs to deviate from its path if there is oncoming traffic. An AV is allowed to drive on the advisory cycle lane, but it might be difficult to properly train AVs for these situations. How often this situation occurs is dependent on traffic volumes. Additionally, the speed difference between AVs and cyclists is still significant when adhering to the speed limit.

Situation 9 - Bicycle lane A cycle lane is evaluated diversely by the experts in terms of complexity and safety. The visual segregation is wider compared to the advisory cycle lane in situation 8, ensuring sufficient space for cyclists overtaking other cyclists. The speed limit is also lower, and the design does not invite speeding. However, the cycle path is still adjacent to the road, meaning cyclists and vehicles drive close to each other.

The infrastructure is clear, meaning an AV will stay in its lane. By law, vehicles are also not allowed to drive on this type of cycle lane [6]. This can make it difficult in emergency situations, as this creates a dilemma for the AV whether to cross the line or not. For human drivers, it is easier to determine if it is accepted in a specific situation to violate the law by crossing the line.

The situation seems to be quite regulated, as everyone is intended to stay in its lane. However, cyclists can easily deviate, as there is no physical segregation. This increases the probability of unexpected cyclist behavior.

Additionally, this is no unambiguous situation according to two experts. There is no standard situation according to Sustainable Safety guidelines, meaning there are many differences throughout the Netherlands. Cycle lanes (both with a solid and broken line) are often used in a situation with many other factors present that may complicate the situation for AVs, such as adjacent parking spots, driveways, pedestrian crossings, or intersections.

5.3.3 Qualitative Interview Results per Surrogate Measure of Safety

This section describes the qualitative results of the interviews for each Surrogate Measure of Safety as determined in Section 4.2.3. The expert statements that could not be related to one of the predefined Surrogate Measures of Safety are

[6] This is different compared to a cycle path with a broken line: drivers may cross the broken line to reach an adjacent parking spot for example

categorized separately. Furthermore, cyclist traffic violations is added as Surrogate Measure of Safety, as it was often mentioned by experts to affect cyclist safety. A more elaborate overview of expert statements per Surrogate Measure of Safety is included in Appendix C.

Degree of segregation According to the experts, complete segregation of cyclist and vehicle flow is desired, especially at high speeds. At junctions, this is often not the case, and signalized intersections are preferred over unsignalized intersections. The degree of segregation in situation 7 (access road) is often mentioned as the main reason causing unsafety, especially in combination with the speed limit. Two experts mentioned the lack of space at what they supposed were bicycle (advisory) lanes. However, the linings are intended as a traffic calming measure, by visually narrowing the road (CROW, 2016). However, a maximum of 25 *cm* from the side of the road is advised for these lines, otherwise, it is often interpreted as bicycle lanes (CROW, 2016). This could also be wrongly interpreted by AVs, if not sufficiently trained in similar situations.

Situation 8 is considered safer, due to the clear advisory bicycle lanes for cyclists. Especially the contrasting color is mentioned as a positive design aspect. However, experts consider this still too small for safe segregation, which is in correspondence with the guidelines in CROW (2016). In both access road situations, an AV has to deviate from the middle of the road and drive towards the side of the road if there is oncoming traffic. As this space is shared with cyclists, it is considered a really complex scenario for AVs. It is difficult to determine how an AV should behave.

Situation 9 (bicycle lane) is evaluated as safer, mainly due to the segregation being more clear. Additionally, cyclists have more space, even sufficient to overtake or cycle next to each other. An AV also has its own space, and (except in emergency situations) does not need to drive on the cyclist path. Furthermore, because of the solid line, it is also not permitted by law to drive on the bicycle lane. However, as cyclists and vehicles are still only visually segregated in this situation, a risk remains that cyclists will deviate from their intended path and cycle on the carriageway.

At the roundabout situations, no expert statements were related to the degree of segregation.

Vehicle speed A high vehicle speed at the conflict situation is often mentioned as a large risk for cyclist safety. Infrastructure design should not let this happen, but where cyclist violations are possible, the risk remains. Reducing vehicle speed at intersections is often mentioned as a possibility to increase cyclist safety. For example in situation 3 (priority intersection with cross traffic), where traffic calming measures are in place. It is mentioned important that an AVs behaves according to the design, and thus reduces its speed in order to increase response time for cyclists unexpectedly crossing. It is possible to reduce AV speed even further to increase safety, but that is not desired for traffic flow. If a reduced speed is required for safely passing a situation, such as a turn or entering a roundabout, it is associated with increased cyclist safety. It is expected that if cyclists have right of way (situations 2, 4, and 6), AV speed is even lower. On the other hand, a low speed also facilitates visual communication, which is difficult for AVs.

In situations where the degree of segregation is problematic and AVs and cyclists might need to share the road (situations 7 and 8), high vehicle speeds are undesirable. The speed limit of 60 km/h is indicated to be too fast for AVs to safely interact with cyclists, e.g. for overtaking. Furthermore, even when overtaking with sufficient space, the subjective safety of cyclists is low. However, HDVs often drive even faster than 60 km/h, especially when the road is sufficiently wide. AVs are expected to drive according to the maximum speed limit.

Cyclist traffic volume As can be seen in Figure 5.6, few expert statements were related to cyclist traffic volume. Although cyclist traffic volume affects cyclist safety due to increased exposure, this shows that it is not expected to have a large impact. In situations where cyclists have priority, it was mentioned several times that larger cyclist volumes cause shorter gaps for AVs. Although not directly affecting cyclist safety, conservative behavior of AVs could result in long waiting times for AVs to pass a cyclist crossing. This could then result in congestion, especially on busy bicycle routes.

In both access road situations, large cyclist volumes is mentioned as problematic. For an AV, it is increasingly difficult to determine its position when there are multiple cyclists in combination with oncoming vehicles. Although most of the time there is little traffic on access roads, such a situation is no exception.

Predictability of behavior Statements related to the predictability of behavior were mentioned most by the experts. Situations with predictable cyclist behavior were evaluated as less complex and safer compared to situations with less predictable cyclist behavior. Predictability of cyclist behavior is important for level 3 of the Situation Awareness theory of Endsley (1995): projection of future status. Better predictability of behavior leads to a better projection of future status and thus increased safety.

One of the main reasons signalized intersections are evaluated least complex is due to the predictability of behavior. Because the situation is fully regulated, cyclist behavior is very predictable, as they should wait for a red light. The only unpredictable action mentioned is red-light running of cyclists, but it is expected AVs can deal with this at least as good as human drivers and supposedly even better. Furthermore, AVs are not expected to run the red light, which is safer for cyclists compared to human drivers who occasionally run the red light. With a permitted conflict present, complexity is slightly increased due to simultaneous green lights, but still considered sufficiently safe for cyclists.

At priority intersections, the absence of formal traffic lights is mentioned as a factor increasing complexity for AVs. This is especially the case if cyclists do not have priority (situation 3), as it can be questionable if a cyclist is intending to stop. However, if cyclists have priority (situation 4), the absence of traffic lights is not seen as a large problem. As an AV should know cyclists have priority and it needs to stop to yield for cyclists, it is clear what to expect. A similar trend is observed for roundabouts. If cyclists have priority (situation 6), almost all experts mentioned cyclist behavior is very predictable. The expected behavior of AVs is clear, as they have to yield for cyclists. At roundabouts where cyclists have no priority (situation 5), cyclist behavior is harder to predict. It is important that AVs can deal with cyclists unexpectedly crossing the road. Some experts suggested it could be safer to give cyclists priority at all roundabouts.

At situations where AVs are not or only visually segregated from cyclists, unexpected behavior of cyclists is also mentioned as problematic. Cyclists do not always behave as they should, and sometimes diverse behavior is allowed. For example at situation 8, where cyclists are allowed to cycle next to each other, even outside the advisory bicycle lane. In situation 9, cyclists could drive partly on the carriageway when overtaking, and it is questionable if this is expected by AVs.

Visibility Visibility is most often mentioned at the priority intersections, where a large difference is present between the situations. In situation 3, the cyclist trajectory before entering the intersection is partly occluded due to the bushes. This is tricky according to multiple experts, especially if the bushes are higher. In situation 4, the conflict situation can clearly be overseen, which is mentioned as a positive difference from the previous situation. Regarding the other situations, if there is a good overview of the conflict situation, it is always mentioned as a positive aspect for cyclist safety. For AVs, clear visibility of a situation is really important to accurately detect and classify cyclists, in order to predict their trajectory and intentions.

Infrastructure clarity Although not mentioned often, unclear or unrecognizable infrastructure is considered to be problematic for AVs. As it is difficult for AVs to drive in non-standard situations, it is important that infrastructure design is according to standards and guidelines. Recognizable infrastructure ensures an AV knows how to behave. For example, the different color and clear lines of the advisory bicycle lane in situation 8 ensures an AV knows cyclists can be expected. On the other hand, the color of the road in situation 3 wrongly suggests that cyclists have priority, which might confuse AVs. Furthermore, lines are missing, which could affect the positioning of an AV.

Another interesting aspect is that many situations are typical Dutch situations, which are not present abroad. Therefore, it is important that AVs are trained in these particular situations and that infrastructure design does not deviate much from standard designs. The standard design is in the Netherlands based on the guidelines of CROW.

Finally, the quality of the infrastructure is mentioned as a problem in situation 6, as it is somewhat deteriorated.

Visual communication required Expert statements related to visual communication required are mentioned least by the experts, as shown in Figure 5.6. The reason for the few mentions probably is because in most situations visual communication is not required or not even possible. However, if mentioned, it is related to a decrease in cyclist safety. Interaction between cyclist and vehicle, such as seeking eye-contact, is especially mentioned in situations where cyclists do not have priority. At low speeds, interaction is possible, and it could be communicated if there is an intention to deviate from the priority rules. This informal behavior happens regularly, as discussed in Hypothesis 2. For AVs, it is difficult to communicate in these scenarios with informal behavior and act accordingly. In situations where cyclists have priority, informal behavior is less likely to happen. Cyclists will less often seek eye-contact, expecting vehicles to yield.

Cyclist detection accuracy Cyclist detection accuracy is the second most mentioned Surrogate Measure of Safety by experts, highlighting the importance of sufficient cyclist detection. Many times, cyclist detection accuracy is mentioned as a hard requirement for permitting AVs on the road. This is logical, as insufficient cyclist detection inherently leads to unsafe situations, making all other Surrogate Measures of Safety not relevant anymore. Therefore, it is important that AVs are extensively tested on detecting cyclists before permitted on Dutch roads.

In general, experts expect from SAE-level 4 AVs that cyclist detection is better compared to human drivers. Due to sensors continuously monitoring the environment, AVs are not distracted like human drivers. Furthermore, 360-degree scanning of the environment improves cyclist detection at two-way cyclist paths. Currently, many accidents happen due to cyclists being overlooked at these two-way cyclist paths (Schepers et al., 2011). In addition, violating behavior of cyclists is also expected to be detected better and faster by AVs compared to human drivers.

A questionable aspect of cyclist detection accuracy is the performance in adverse weather conditions. Using sensor fusion, so combining RADAR, LIDAR, and vision-based technologies is suggested to improve cyclist detection.

Cyclist traffic violations As discussed in Section 5.3.1, cyclist traffic violations is added as a separate Surrogate Measure of Safety, because it was often mentioned by experts to affect cyclist safety. Logically, it is mentioned fewer times for situations where cyclists have priority, as fewer violations are possible. Red-light running is often mentioned as a risk at signalized intersections. However, it is expected that AVs can better respond to red-light running than HDVs, especially when lowering their speed at the intersection.

Another possible violation is that cyclists take right of way when having no priority, either consciously or unconsciously. This is multiple times mentioned as a risk in situations 3 and 5, both where cyclists have to yield for vehicles. It is considered a larger problem in situation 3, mainly because the vehicle speed is higher at the conflict situation.

The last possible violation mentioned is cyclists coming from the wrong direction. Due to continuously scanning the environment in all directions, it is expected that AVs can better detect cyclists in this scenario than HDVs.

Other Multiple interesting arguments were given that could not be classified into the predefined Surrogate Measures of Safety:

- *Sensitivity/conservativeness*: Conservative behavior of AVs is often mentioned as an argument for increased cyclist safety, compared to interaction with HDVs. It is expected that AVs would not accept all gaps that human drivers would accept, which can lead to congested situations in case of large cyclist volumes.
- *HD-map*: Use of an HD-map is multiple times mentioned as an assumption or prerequisite for AVs. The HD-map should include information on the priority rules.
- *Communication AV with traffic lights*: At intersections with traffic lights, multiple experts mention communication between the AV and the traffic light as an assumption or prerequisite.
- *Cyclist type*: One expert mentioned different behavior per cyclist type, as discussed in Hypothesis 1. The expert mentioned that it is desirable that AVs adjust their behavior based on cyclist type.
- *Subjective safety*: Despite the actual safety level, subjective safety is also important to retain the favorable position of cyclists. If cyclists perceive the interaction with AVs as insufficiently safe, this can result in an uncomfortable feeling for cyclists.
- *One-way vs two-way direction*: When cyclists can come from two ways, it is often associated with higher risk. However, it is expected that AVs can better detect cyclists coming from two ways compared to human drivers.
- *Interaction AV with HDVs*: A second-order effect is mentioned caused by the interaction between AVs and HDVs. Human drivers might not expect certain behavior of AVs, or can be irritated due to conservative driving behavior of AVs. This can lead to dangerous traffic situations, which can affect cyclist safety.

5.4 Conclusions

Although multiple accident risk factors are identified, SAE-level 4 AVs are in general evaluated by the experts to positively affect cyclist safety. When permitting AVs on Dutch roads, it is important to take into account these risk factors when determining the Operational Design Domain (ODD). If a situation is considered to be potentially hazardous for cyclists, AVs should not be permitted in similar situations.

For assessing cyclist safety, a division can be made between road sections and junctions. Road sections are evaluated to be more dangerous if cyclists are not physically segregated from vehicles, such as at access roads. Especially unpredictable behavior of cyclists is mentioned as an accident risk factor for AVs. Other risk factors identified for not physically segregated road sections are high vehicle speeds, lack of space, and visual communication required. This resulted in access roads being evaluated as unsafest of all situations presented to the experts.

To avoid continuous conflicts between AVs and cyclists, road sections without physical segregation between cyclists and vehicles should initially be excluded from the ODD of SAE-level 4 AVs. If physical segregation at road sections is a requirement for permitting AVs, many accident risk factors are avoided. As almost all provincial roads in Noord-Holland physically segregate cyclists and vehicles at road sections, a large network could still potentially be included in the initial ODD.

When excluding these road sections, the number of conflict situations between AVs and cyclists would be greatly reduced, occurring only at junctions. For each specific junction, cyclist safety could be assessed based on the identified Surrogate Measures of Safety. Based on the results of the expert interviews, multiple accident risk factors for junctions are identified. The predictability of behavior is important for correct Situation Awareness. This predictability is increased with clear priority rules, such as at signalized intersections. At priority intersections, cyclists having priority is desired. Other risk accident factors are high vehicle speeds, cyclist violations, and unclear infrastructure. Signalized intersections are evaluated safest by the experts.

Furthermore, sufficiently accurate cyclist detection is mentioned by the experts as a requirement for AVs, before being permitted on Dutch roads where cyclists can be encountered. For proper cyclist detection, it is essential that the conflict situation and cyclist trajectory are not occluded.

Highlights

- In general, SAE-level 4 AVs are evaluated by the experts to positively affect cyclist safety
- Frequently mentioned accident risk factors are high vehicle speeds, unclear infrastructure, occluded conflict situations, and traffic violations by cyclists
- Based on the expert interviews, cyclist traffic violations is added as Surrogate Measure of Safety: *The extent to which the conflict situation facilitates cyclist traffic violations*
- **To avoid continuous conflicts between AVs and cyclists, physical segregation at road sections is taken as a requirement for the remainder of this study**
- Sufficiently accurate cyclist detection by AVs is taken as a requirement for the remainder of this study, otherwise AVs will not be permitted on Dutch roads where cyclists can be encountered

6 Infrastructure Readiness in the Province of Noord-Holland

This chapter provides the results of the analysis of the infrastructure readiness in the province of Noord-Holland for a safe interaction between Automated Vehicles (AVs) and cyclists. First, the defined Surrogate Measures of Safety are classified into three different safety levels. Section 6.1 provides an explanation of this classification, including a rubric to assess the safety of conflict situations. Before presenting the results, Section 6.2 gives some additional information on the road infrastructure network in the province of Noord-Holland. Afterward, Section 6.3 gives two examples of how the rubric is used for the analysis of the road network. Section 6.4 provides the results, including an overview of common risk factors for each Surrogate Measure of Safety. An elaborate overview of results is included in Appendix E. Methods to minimize the risk factors and thereby promoting road safety are suggested in Section 6.5, linking them to the hypotheses defined in Section 3.4. Finally, Section 6.6 provides an overview of the conclusions of this chapter.

6.1 Classification of Surrogate Measures of Safety

As concluded in Section 5.4, by initially excluding road sections without physical segregation between cyclists and vehicles from the Operational Design Domain (ODD), continuous conflicts present at road sections are avoided. For the remaining conflict situations at junctions, cyclist safety can be assessed by scoring the performance on each Surrogate Measure of Safety. Two of the listed Surrogate Measures of Safety in Section 4.2.3 are not included in the assessment. Instead, they are defined as requirements for permitting AVs in situations where cyclists could be encountered. As mentioned before regarding the degree of segregation, road sections need to be physically segregated for cyclists and vehicles. Furthermore, cyclist detection accuracy needs to be sufficient. Without these requirements, allowing AVs on Dutch roads is expected to be detrimental to cyclist safety. Additionally, an HD-map of the ODD needs to be included in the AV software. Finally, although not discussed in this study, safe overtaking by the human driver outside the ODD is required.

Based on the results from the expert interviews (Section 5.3), cyclist safety analysis (Chapter 4), and literature review (Chapter 3), different safety levels are distinguished for each Surrogate Measure of Safety. A division is made between three different safety levels, to provide an adequate, a problematic, and an intermediate safety level. Adding additional safety levels will increase the difficulty of determining the specific characteristics of each safety level. The safety levels, derived from Wijlhuizen et al. (2014), are defined as follows:

- *Adequate*: Safety level is sufficient for AV/cyclist interaction
- *Point of attention*: Safety level leads to minor risks for cyclist safety
- *Problem area*: Safety level leads to major risks for cyclist safety

For each Surrogate Measure of Safety, the reasoning behind the classification is discussed in this section. A rubric with an overview of the classification of Surrogate Measures of Safety for junctions is displayed in Table 6.1.

Vehicle speed A low vehicle speed at the conflict situation is desired, as the cyclist fatality rate strongly increases with vehicle speed (as shown in Figure 4.1). A speed limit of 70 km/h is often present at signalized intersections, and 80 km/h at priority intersections at provincial roads where vehicles have priority. Currently, a speed limit of 80 km/h is accepted on the majority of provincial roads. Therefore, it is considered to be sufficiently safe, even at conflict situations where cyclists can be encountered. As AVs are expected to have shorter response times than human drivers, it is expected that cyclist safety will not decrease at conflict situations with these speeds. However, there is still a risk, and therefore it is classified as a point of attention. Lowering the speed decreases both vehicle stopping distance and the chance of cyclist fatality. Experts evaluated a signalized intersection with a speed of 70 km/h to be sufficiently safe for AV/cyclist interaction, also due to the combination with predictable cyclist behavior. A vehicle speed less than 50 km/h is preferred, as this highly decreases stopping distance and results in forgiveness of other road users' mistakes or violations. This forgiveness in design is also a main aspect of Sustainable Safety (SWOV, 2018).

Cyclist traffic volume Contrary to interaction with human drivers, cyclist traffic volume is not expected to have a large influence on cyclist safety. Many bicycle-motor vehicle accidents currently happen due to cyclists being overlooked by human drivers. It is expected that AVs can better detect cyclists due to continuously monitoring the environment in 360 degrees. If cyclist detection accuracy is not sufficient, AVs will not be permitted on Dutch roads with possible conflict situations with cyclists. Therefore, cyclist traffic volume is not expected to significantly affect cyclist safety. However, high cyclist volumes can lead to congestion due to conservative behavior of AVs, not accepting gaps a human driver would have accepted. This can lead to irritation of other road users, resulting in possible secondary safety effects. Furthermore, an increase in cyclist volume always means there is more exposure to cyclists, thus more chance of accidents. Therefore, a low or medium cyclist volume is considered adequate, and high cyclist volumes are a point of attention. The exact volumes corresponding with the safety levels need to be determined. However, this is difficult to determine a specific volume for all situations, as it is highly dependent on conflict type (CROW, 2016).

Predictability of behavior As Surrogate Measure of Safety mentioned most by experts, predictability of behavior is found to be really important for a safe interaction between AVs and cyclists. The unpredictability of cyclist behavior is often mentioned as a major challenge for AVs in urban areas. However, predictability of behavior is difficult to measure and subsequently to qualitatively distinguish in safety levels. Therefore, a distinction is made based on the type of conflict situation leading to (un)predictable behavior. As concluded from the expert interviews, signalized intersections lead to predictable behavior, due to clearly regulated priority rules. Additionally, situations where cyclists have priority are associated with better predictability. These situations are easy for AVs, as they always have to yield for cyclists, and cyclists will continue their path as they expect that vehicles will yield. However, if cyclists have no priority, the chance of unexpected behavior is larger. Sometimes, cyclists unexpectedly cross the road if they think the gap is sufficient. Although this is not allowed, it can confuse AVs. Therefore, priority intersections where cyclists have priority are marked as a point of attention. In situations where clear priority rules are absent, such as non-priority intersections or shared spaces, cyclist behavior is very diverse. This makes it really difficult to predict, and therefore these conflict situations are considered to be problematic.

Visibility For a safe interaction between AVs and cyclists, a clear overview of the conflict situation and cyclist trajectory path is needed. If one of these is (partly) occluded, Situation Awareness is seriously deteriorated, affecting cyclist safety. Therefore, it is classified as a problem area. If the conflict situation or cyclist trajectory could be (partly) occluded due to a certain reason, it is marked as a point of attention. An example could be that not maintained vegetation results in occlusion of the cyclist trajectory path. If there is a clear overview of both the conflict situation and cyclist trajectory path, the visibility is adequate.

Infrastructure clarity As defined in Section 4.2.3, infrastructure clarity consists of two aspects: being clear and recognizable. Clear infrastructure means a good quality of linings and road signs, such that an AV can accurately navigate over the road and priority rules are clear. If quality is deteriorated or road signs are missing, this is marked as a point of attention. It is not classified as a problem area, because this should be compensated for by the information included in the HD-map. Regarding recognizability, a conflict situation should be according to CROW guidelines, such that AVs are familiar with the situation. Minor adjustments are acceptable, but situations significantly different from the guidelines are marked as a problem area. This is also related to homogeneity, which increases AV performance. As not all different situations will be trained adequately, less common, not standard, situations are also considered a problem area.

Visual communication required If visual communication is required to safely pass a conflict situation, it is associated with lower cyclist safety. Desirably, it is expressed as the percentage of interactions that require visual communication, but that requires an elaborate study. Therefore, a classification is made based on the design of the infrastructure. If the design does not facilitate visual communication, such as high vehicle speeds or clear priority rules, the safety level is considered as adequate. If the design facilitates visual communication in certain specific scenarios, it is considered to be a point of attention. An example is possible informal behavior when multiple vehicles are waiting to enter a roundabout where cyclists have no priority. When exiting such a roundabout, vehicles are accelerating and informal behavior is less frequent. When the purpose of the infrastructure is to communicate, it is indicated as a problem area. Examples are shared spaces or non-priority intersections, as priority is often determined by visual communication. However, similar situations are not frequently expected on provincial roads.

Cyclist traffic violations Cyclist traffic violations, either consciously or unconsciously, negatively affect cyclist safety. Desirably, it is expressed as the number of traffic violations per conflict situation. However, as this requires very specific data that is often not present, it is not possible to analyze each conflict situation in such detail. Again, a classification is made based on the design of the infrastructure. If the design facilitates traffic violations, either consciously or unconsciously, it is indicated as a problem area. Examples are a small distance from the cycle path to the carriageway, where cyclists have bad visibility of oncoming vehicles. At traffic lights, a small waiting area or not credible waiting times for cyclists lead to violations (Kennisnetwerk SPV, 2019). If infrastructure design facilitates occasional violations, it is marked as a point of attention. An example is a crossing with a single lane where cyclists can accept a very small gap between vehicles. A conflict situation is marked as adequate if almost no violations are facilitated, such as cyclists having priority on a two-way cycling path.

An increased difficulty for determining the safety level for this specific Surrogate Measure of Safety is the behavioral adaptation of cyclists towards AVs. This can be either risk-averse or more risk-taking, leading to different numbers of traffic violations.

Table 6.1: Classification of Surrogate Measures of Safety to assess road safety at junctions

Surrogate Measure of Safety*	**Adequate**	**Point of attention**	**Problem area**
Vehicle speed	<50 km/h	50 – 80 km/h	>80 km/h
Cyclist traffic volume	Low; Medium	High	
Predictability of behavior	Signalized intersection; Priority intersection (cyclists having priority)	Priority intersection (AVs having priority)	Non-priority intersection; Shared space
Visibility	Clear overview of conflict situation and cyclist trajectory path	Conflict situation or cyclist trajectory path could be (partly) occluded	Conflict situation or cyclist trajectory path (partly) occluded
Infrastructure clarity	Good quality of road surface markings and situation is according to CROW guidelines	Deteriorated quality of road surface markings or missing road signs	Situation is not according to CROW guidelines; No standard (trained) situation
Visual communication required	Seldom: design of infrastructure does not facilitate visual communication	Sometimes: design of infrastructure facilitates visual communication in certain specific scenarios	Often: purpose of infrastructure is to communicate
Cyclist traffic violations	Seldom: infrastructure facilitates almost no violations	Sometimes: infrastructure facilitates occasional violations	Often: infrastructure facilitates violations (consciously or unconsciously)

**Degree of segregation and cyclist detection accuracy are not included, as these are taken as a requirement for road safety: road sections must be physically segregated and cyclists need to be accurately detected and classified by AVs*

6.2 Road Infrastructure Network in Noord-Holland

Several provincial roads in the province of Noord-Holland will be analyzed to give an overview of current conflict situations between cyclists and vehicles. Each specific conflict situation will be scored on each Surrogate Measure of Safety, according to the rubric of Table 6.1.

The Provincie Noord-Holland specifies three different types of roads, based on their management quality level: VM+, VM0, and VM- roads. VM+ roads are the most important roads for traffic management, often with a connecting function, while VM- roads are the least important for traffic management. For the analysis of the road network in Noord-Holland, the focus is on VM+ roads. An overview of roads for each traffic management quality level is given in Table 6.2. It is possible that a road number is mentioned twice, as different road sections can have different quality levels. A map of the road infrastructure network in Noord-Holland, including quality levels, is included in Appendix D.

Table 6.2: Traffic management quality level of provincial roads in Noord-Holland *(VM+ is most important for traffic management, VM- is least important for traffic management)*

VM+	N194, N200, N201, N203, N205, N207, N208, N235, N236, N239, N242, N244, N246, N247, N250, N307, N505, N513, N516, N524
VM0	N202, N205, N231, N232, N240, N244, N246, N247, N248, N417, N508, N522
VM-	N197, N201, N206, N231, N232, N239, N240, N241, N243, N245, N248, N249, N307, N403, N415, N501, N502, N503, N506, N508, N509, N510, N511, N512, N513, N514, N515, N516, N517, N518, N519, N520, N523, N525, N526, N527

6.3 Analysis of the Road Infrastructure Network

For multiple provincial roads in Noord-Holland, all potential conflict situations between AVs and cyclists are scored based on the rubric in Table 6.1. As cyclist traffic volumes are not available for the majority of conflict situations, this Surrogate Measure of Safety is not taken into account. An example of a conflict situation with minor cyclist safety risks is shown in Figure 6.1. Due to AVs having priority, predictability of behavior is a point of attention. Furthermore, there is a clear overview of both the conflict situation and cyclist trajectory path. The infrastructure quality is good and according to CROW guidelines, and its design does not facilitate visual communication or cyclist traffic violations due to the vehicle speed. Therefore, cyclist safety is considered sufficiently safe and this situation could be included in the Operational Design Domain of AVs.

Figure 6.1: Example of a conflict situation with minor cyclist safety risks (N243 #1)

An example of a conflict situation with major cyclist safety risks is shown in Figure 6.2. The cyclist trajectory path is occluded by the tree, which makes accurate cyclist detection difficult. Furthermore, the traffic calming measure results in a low vehicle speed, facilitating visual communication and informal behavior. It is also not very clear that cyclists do not have priority, and cyclist violations are facilitated due to the low speeds and small distance to cross the road. Due to these reasons, this situation should not be included in the ODD of AVs based on the expected negative effects on cyclist safety.

Figure 6.2: Example of a conflict situation with major cyclist safety risks (N200 #1)

Similar to the situations in Figures 6.1 and 6.2, all conflict situations on multiple provincial roads are scored based on the rubric. This results in an overview for each road, as presented in Table 6.3 for the N197. In total, the N197 has a length of 5.1 *km*, and 8 potential conflict situations with cyclists are present. As can be seen in the figure, the conflict situations score good (green) on most of the Surrogate Measures of Safety. The visibility is almost always sufficient, and infrastructure clarity is good. However, there are some potentially dangerous conflict situations, especially locations #2, #3, #5, and #6, as they have a problematic score (red), or multiple points of attention (yellow). At roundabouts where cyclists have no priority, cyclists sometimes take right of way, either consciously or unconsciously. This does not happen often, but it is certainly a point of attention for AVs. Furthermore, before entering such a roundabout, visual communication is sometimes facilitated due to the low vehicle speeds, especially if congested. This is also not defined as a problem area, but it is something that AVs might need to deal with. The visibility at conflict situation #5 is considered problematic, due to the cyclist trajectory path being occluded by trees.

More elaborate results for the N197 and other provincial roads are provided in Appendix E, the most important results of which are described in Section 6.4.

Table 6.3: Overview of conflict situations and their safety scores for the N197

Road	ID	HMP	Conflict situation	Speed	Predictability	Visibility	Infrastructure clarity	Communication	Violations
N197	#1	3,7	Signalized intersection	50	Signalized	Clear overview	Good	Seldom	Seldom
N197	#2	4,2	Signalized intersection	50	Signalized	Clear overview	Good	Sometimes	Sometimes
N197	#3	5,7	Roundabout (AV priority)	<50	Priority (AV)	Clear overview	Good	Sometimes	Sometimes
N197	#4	5,8	Roundabout (AV priority)	<50	Priority (AV)	Clear overview	Good	Seldom	Sometimes
N197	#5	6,8	Roundabout (AV priority)	<50	Priority (AV)	Occluded	Good	Seldom	Sometimes
N197	#6	7,7	Roundabout (AV priority)	<50	Priority (AV)	Clear overview	Good	Sometimes	Sometimes
N197	#7	7,8	Roundabout (AV priority)	<50	Priority (AV)	Clear overview	Good	Seldom	Sometimes
N197	#8	8,5	Roundabout (cyclist priority)	<50	Priority (cyclist)	Clear overview	Good	Sometimes	Seldom

6.4 Results

In total, 163.51 *km* of provincial roads (N-roads) in the province of Noord-Holland is analyzed, corresponding with 26.6% of the total road network where the Provincie Noord-Holland is the road authority. An overview of analyzed roads is presented in Table 6.4, including the total length and number of conflict situations. All roads are analyzed in the direction with ascending hectometer posts, also referred to as the right direction. As some roads have road sections with different VM-levels, the separate numbers do not add up to the total of 14. A general overview of conflict situations is presented in Section 6.4.1, whereas more specific risk factors per Surrogate Measure of Safety are discussed in Section 6.4.2. An elaborate overview of results for all conflict situations is included in Appendix E.

Table 6.4: Overview of roads analyzed

VM-level	Roads analyzed	Length	Conflict situations (per km)
VM+	7 (N194, N200, N201, N203, N205, N207, N208)	87.88 *km*	52 (0.59)
VM0	4 (N202, N205, N231, N232)	34.77 *km*	33 (0.95)
VM-	6 (N197, N201, N206, N231, N232, N243)	40.86 *km*	33 (0.96)*
Total	14	163.51 *km*	118 (0.75)*

**The N206 is not taken into account for these calculations, as continuous conflicts are present due to not physically segregated road sections*

6.4.1 Overview of Conflict Situations

Tables 6.5, 6.6, and 6.7 give an overview of the conflict situations for respectively VM+, VM0, and VM- roads. An important note that needs to be made is that more conflict situations does not necessarily correspond with a decrease in cyclist safety. However, as there are more locations where cyclists can be encountered, the exposure of cyclists increases.

VM+ roads For the analyzed roads, the average number of conflict situations per kilometer is lowest for VM+ roads. The N207 is the only road without conflict situations: i.e. the road section that is managed by the Provincie Noord-Holland, as the remainder of the N207 is not analyzed. The number of conflict situations varies over the different roads, with the N200 as an outlier. A total of 17 potential conflict situations between AVs and cyclists are identified in 6.45 *km*. Many conflict situations on the N200 are really specific, as they are located close to the beach in Zandvoort. The majority of conflict situations at VM+ roads are signalized intersections. Especially if the N200 is not taken into account, almost 90% of conflict situations are at a signalized intersection.

Table 6.5: Overview of conflict situations on VM+ roads

		Conflict situations					
Road	**Length (km)**	**Total**	**Per km**	**Signalized**	**Priority**	**Roundabout**	**Other**
N194	15,94	3	0,19	1	2	0	0
N200	6,45	17	2,63	1	4	3	9
N201	18,13	8	0,44	8	0	0	0
N201	7,55	4	0,53	3	0	1	0
N203	11,91	8	0,67	7	1	0	0
N205	9,78	1	0,10	1	0	0	0
N207	8,11	0	0,00	0	0	0	0
N208	10,01	11	1,10	11	0	0	0
Total	**87,88**	**52**	**0,59**	**32 (62%)**	**7 (13%)**	**4 (8%)**	**9 (17%)**

VM0 roads An overview of conflict situations on the analyzed VM0 roads is given in Table 6.6. As can be seen, the diversity in the number of conflict situations per road is again large. On average, the number of conflict situations per kilometer is higher compared to VM+ roads. The number of priority intersections and roundabouts is higher, thereby lowering the share of signalized intersections. The only road without conflict situations was the N205. It is interesting to mention that another part of the N205 is a VM+ road, which can be of influence for the separation of cyclist and vehicle streams.

Table 6.6: Overview of conflict situations on VM0 roads

		Conflict situations					
Road	**Length (km)**	**Total**	**Per km**	**Signalized**	**Priority**	**Roundabout**	**Other**
N202	6,48	6	0,93	1	4	0	1
N205	8,14	0	0,00	0	0	0	0
N231	5,78	16	2,77	4	5	5	2
N232	9,80	8	0,82	6	1	1	0
N232	4,57	3	0,66	3	0	0	0
Total	**34,77**	**33**	**0,95**	**14 (42%)**	**10 (30%)**	**6 (18%)**	**3 (9%)**

VM- roads Similar results can be seen for VM- roads, as shown in Table 6.7. The number of conflict situations per kilometer is almost the same as for the VM0 roads analyzed, with conflict situations present on all roads. The share of present conflict situations is also comparable. The N206 is not taken into account in the table, as cyclists are not physically segregated at multiple road sections. Next to these continuous conflicts, multiple other conflict situations are present. Therefore, the N206 has too many problematic risk factors for a safe interaction between AVs and cyclists.

Table 6.7: Overview of conflict situations on VM- roads

		Conflict situations					
Road	**Length (km)**	**Total**	**Per km**	**Signalized**	**Priority**	**Roundabout**	**Other**
N197	5,07	8	1,58	2	0	6	0
N201	4,78	1	0,21	1	0	0	0
N206*	*6,56*	-	-	-	-	-	-
N231	5,51	8	1,45	5	3	0	0
N232	2,80	2	0,71	0	0	2	0
N243	16,14	14	0,87	5	8	1	0
Total	**34,29***	**33**	**0,96**	**13 (39%)**	**11 (33%)**	**9 (27%)**	**0 (0%)**

** N206 is not taken into account, as cyclists are not physically segregated at road sections, leading to continuous conflicts*

Tables 6.5, 6.6, and 6.7 show that a diversity of conflict situations is present on provincial roads in the province of Noord-Holland. Most of the conflict situations can be classified into the earlier identified potential conflict situations in Section 4.3. Signalized intersections, priority intersections, and roundabouts all frequently occur on the analyzed roads. Whereas the share of signalized intersections is largest for VM+ roads, priority intersections and roundabouts are more often present on VM0 and VM- roads. However, there are also some other conflict situations present. The results furthermore show that it cannot be said that a road of a certain VM-level has by definition more or less conflict situations than another VM-level. For the remainder of the provincial roads that are not analyzed, it is thus important that each road is analyzed in detail to assess its safety.

6.4.2 Overview of Risk Factors

For each Surrogate Measure of Safety specifically, the results are discussed. Although not all identified risk factors can be presented in detail, some risk factors are illustrated by discussing examples of conflict situations. It is important to highlight that certain risk factors are also present for human drivers. However, based on the characteristics of AVs discussed in e.g. Sections 3.2.5 and 4.2.2, it is expected that the identified risk factors are more important for AVs.

Vehicle speed No problematic conflict situations are identified, as vehicle speed at all conflict situations is at most 80 km/h. Especially at signalized intersections, the speed limit is often temporarily reduced to 70 or even 50 km/h. At roundabouts, the actual vehicle speed at the conflict situation is <50 km/h. The large majority of conflict situations have a vehicle speed that is still 50 to 80 km/h, which is classified as a point of attention. It is not considered to be problematic, as currently these speeds are also accepted with human drivers. However, as the cyclist fatality rate is very high with similar impact speeds, it certainly remains a point of attention. It has to be noted that the speed range corresponding to 'point of attention' is quite large, and lower speeds within this range are safer than higher speeds.

Predictability of behavior Most of the conflict situations are signalized, meaning cyclist behavior is quite predictable and thus classified as adequate. This is especially the case at VM+ roads. Cyclists occasionally have priority, such as at some roundabouts at the beginning or end of a provincial road. Furthermore, cyclists often have no priority at conflict situations, such as at priority intersections and roundabouts. This is marked as a point of attention, as it can sometimes happen that cyclists do not behave as expected. The only road where a problematic predictability of behavior was identified, is the N200. In total, the road infrastructure at 8 conflict situations suggested there was a shared space, as illustrated in Figure 6.3. Such a shared space situation causes cyclist behavior that is difficult to predict.

Figure 6.3: Example of a conflict situation with problematic predictability of behavior (N200 #13)

Visibility Reduced visibility of the cyclist trajectory path is considered to be problematic in a total of 10 situations (the exact locations can be found in Appendix E). The occlusion is, for example, caused by bushes, trees, or a fence. Occlusion of the cyclist trajectory path is not always directly dangerous, as often cyclists have no priority. However, the Situation Awareness of AVs is highly reduced, which is not desired. Therefore, reduced visibility of cyclists is always marked as a problem area. The visibility is marked as a point of attention in two situations, as the cyclist trajectory path could be occluded: due to a bicycle parking (N202 #6) or bushes (N243 #10) next to the road. An example of problematic visibility is presented in Figure 6.4. The trajectory path of cyclists from the right is occluded by the trees, causing a reduced Situation Awareness for the AV.

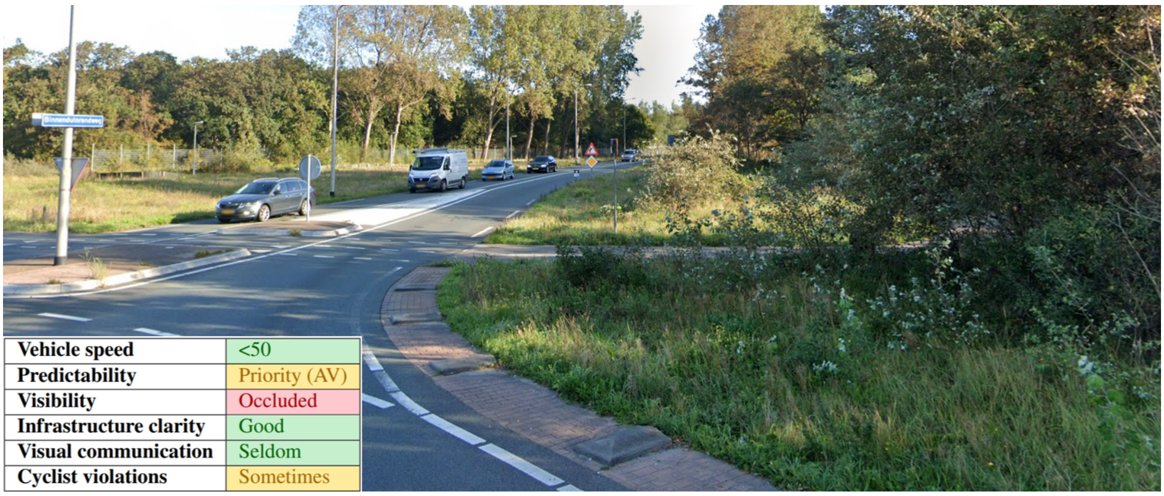


Figure 6.4: Example of a conflict situation with problematic visibility (N197 #5)

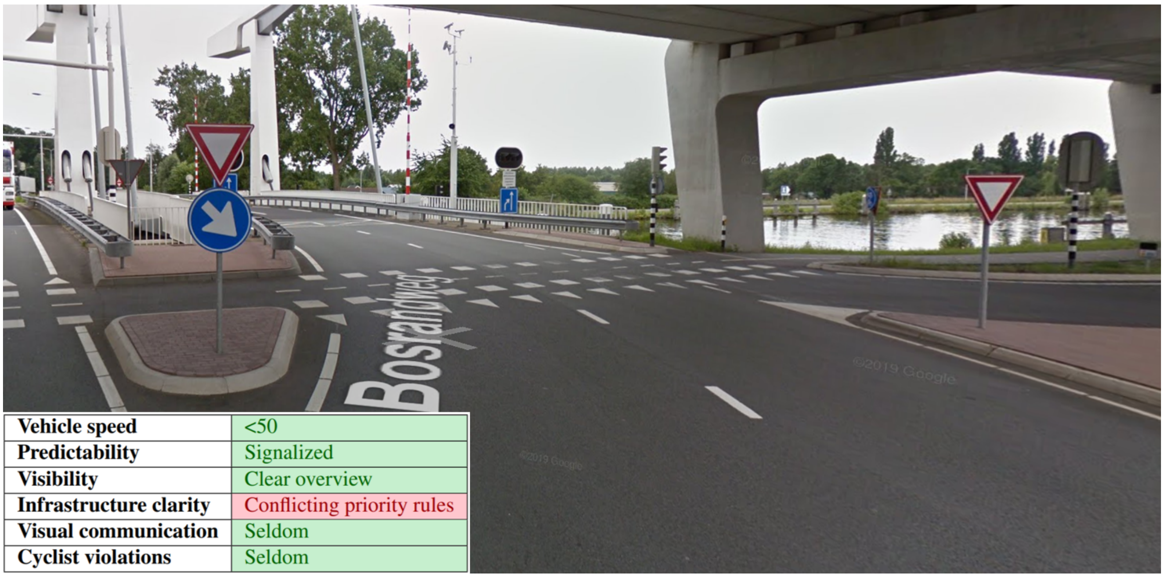
Another conflict situation with problematic visibility is shown in Figure 6.5. Again, the cyclist trajectory path at the right side is occluded. As the intersection is signalized and priority is thus regulated, this is not directly a problem. However, it can still happen that a cyclist suddenly appears from behind the hedge, resulting in more difficulty for the AV to predict the future status of the cyclist. Therefore, this is also classified as a problem area. The other conflict situations with problematic visibility are mostly similar situations where the trajectory path of cyclists coming from the right is (partly) occluded.

Figure 6.5: Example of a conflict situation with problematic visibility (N205 #1)

Infrastructure clarity In the majority of situations, infrastructure clarity was sufficient. This is also what can be expected based on the assessment of road quality by KPMG (2020). However, some risk factors were identified. Sometimes, infrastructure was marked as unclear when road surface markings to indicate a cyclist crossing were missing. An example is presented in Figure 6.6, where the bicycle path on the right facilitates crossing cyclists. However, road linings indicating a cyclist crossing are not present, which can ensure AVs do not expect cyclists crossing at this location. These missing road surface markings were observed at 9 conflict situations on the analyzed roads, often referred to as ‘no official conflict’.

Figure 6.6: Example of a conflict situation with unclear infrastructure clarity (N231 #24)

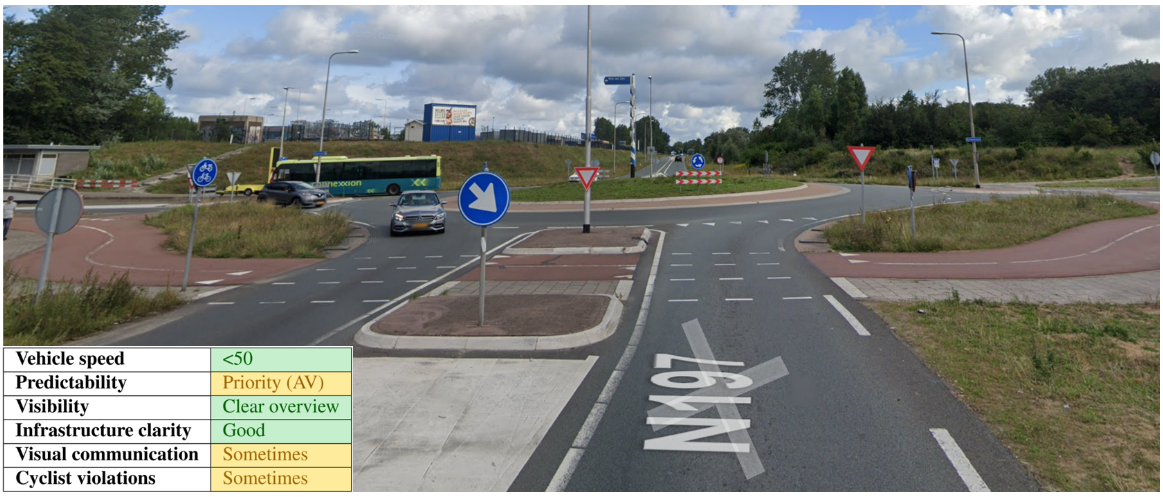
Two times, conflicting priority rules resulted in a problematic classification. An example is given in Figure 6.7 for the turn from the N232 towards the N231. Although the intersection is regulated by traffic lights, the road surface markings suggest a priority intersection where cyclists have right of way. It is unclear why this situation has conflicting priority rules, but it is confusing for an AV. Another example of problematic infrastructure clarity can be seen in Figure 6.3, where the shared space is no standard situation for provincial roads.



Vehicle speed	<50
Predictability	Signalized
Visibility	Clear overview
Infrastructure clarity	Conflicting priority rules
Visual communication	Seldom
Cyclist violations	Seldom

Figure 6.7: Example of a conflict situation with problematic infrastructure clarity (N232 #12)

Visual communication required Visual communication is sometimes required to safely pass a conflict situation. For example, at roundabouts where cyclists do not have priority, such as in Figure 6.8, the design facilitates visual communication. Due to the relatively low speeds and the fact that vehicles are decelerating, visual communication is possible. Especially if congested, and vehicles are waiting to enter the roundabout, visual communication is used by cyclists to see if they can safely cross. This informal behavior sometimes happens in these situations, which is a point of attention for AVs. When exiting a similar roundabout, visual communication is seldom facilitated due to the fact that vehicles are accelerating and do not have to wait to exit the roundabout. In general, higher vehicle speeds do not facilitate visual communication, whereas lower vehicle speeds do. Another situation where visual communication is sometimes used by cyclists, is at roundabouts where cyclists have priority. Cyclists sometimes use visual communication to verify if they have been seen.



Vehicle speed	<50
Predictability	Priority (AV)
Visibility	Clear overview
Infrastructure clarity	Good
Visual communication	Sometimes
Cyclist violations	Sometimes

Figure 6.8: Example of a conflict situation facilitating visual communication and cyclist violations (N197 #3)

Cyclist violations During the expert interviews, many experts mentioned that cyclists taking right of way at roundabouts is a risk factor, such as at the conflict situation in Figure 6.8. Either consciously or unconsciously, it is expected that this sometimes happens. Although the cyclist is wrong by violating the priority rules, it is a type of behavior that an AV needs to be able to deal with. Human drivers can anticipate on cyclists who might take right of way e.g. by additional head checks, possibly based on their own cycling experience. Especially if the cyclist path is straight, leading to a higher cyclist speed, occasional violations are facilitated. Another situation leading to occasional cyclist violations is shown in Figure 6.9. The small crossing distance, especially in combination with a relatively low vehicle speed, facilitates cyclist violations. Additionally, cyclists sometimes use visual communication in similar scenarios to verify if they can safely cross in front of an arriving vehicle.

Vehicle speed	50
Predictability	Priority (AV)
Visibility	Clear overview
Infrastructure clarity	Good
Visual communication	Sometimes
Cyclist violations	Sometimes

Figure 6.9: Example of a conflict situation facilitating visual communication and cyclist violations (N194 #1)

Even very specific situations can lead to a point of attention regarding cyclist violations, which makes it very difficult for AVs. An example is shown in Figure 6.10. As the vehicle speed is 80 km/h, the infrastructure is not inviting for cyclists to violate the priority rules. However, the presence of a bus stop nearby indicates that cyclists wanting to cross might be in a hurry to catch the bus. A human driver might understand a certain scenario, especially if a bus is waiting at the bus stop. However, for an AV it is very difficult to understand such a detailed assessment of Situation Awareness.

Vehicle speed	80
Predictability	Priority (AV)
Visibility	Clear overview
Infrastructure clarity	Good
Visual communication	Seldom
Cyclist violations	Sometimes

Figure 6.10: Example of a conflict situation facilitating occasional cyclist violations (N232 #9)

6.5 Promoting Road Safety at Conflict Situations

Based on the results of the infrastructure readiness analysis, some suggestions can be made to promote road safety between AVs and cyclists. It has to be noted that certain accident risk factors are also present for HDVs (Human Driven Vehicles). However, human drivers are expected to anticipate better on these situations based on their experience. In Section 6.5.1 the main risk factors are discussed and linked to the hypotheses on how to promote road safety as defined in Section 3.4. Section 6.5.2 provides infrastructure adjustments to promote road safety in the province of Noord-Holland.

6.5.1 Methods to Promote Road Safety

Hypothesis 1 - Cyclist type One expert mentioned different behavior can be expected for different cyclist types. The behavior of a racing cyclist or a parent with a child is different at e.g. roundabouts where cyclists have no priority. In these situations, cyclist traffic violations was found to be a point of attention. It is likely that cyclist types who are more risk-taking violate the formal traffic rules more often than risk-averse cyclist types. Classifying different cyclist types is thus expected to aid in correctly predicting cyclist intentions.

Hypothesis 2 - Informal behavior Situations where visual communication is required are evaluated by the experts to be difficult for AVs. Many conflict situations are marked as a point of attention because visual communication is facilitated, leading to informal behavior. Especially at roundabouts where cyclists do not have priority, visual communication required is a point of attention. The relatively low vehicle speed when entering such roundabouts, especially if congested, facilitates visual communication and informal behavior. To correctly predict cyclist intentions in these situations, AVs need to be able to take into account this informal behavior.

Hypothesis 3 - Behavioral adaptation Cyclist traffic violations is frequently mentioned by the experts as an accident risk factor. If cyclists show more risk-taking behavior when interacting with AVs compared to HDVs, this might lead to more cyclist violations. This behavioral adaptation can become a problem at e.g. roundabouts where cyclists do not have priority, as occasional violations are already facilitated by its design. As the actual difference in cyclist behavior towards HDVs and AVs is yet unknown, roundabouts where cyclists do not have priority remain a point of attention and should be handled with caution.

Hypothesis 5 - Safe driver behavior Increased conservative behavior when encountering cyclists is mentioned by multiple experts as expected behavior of AVs. It is found that, especially at signalized intersections, vehicle speed is often reduced at conflict situations, which is an example of safe behavior towards cyclists. This increases cyclist safety, as cyclist fatality rate in case of an accident is significantly affected by vehicle speed (CROW, 2016). The difference in cyclist fatality rate for an impact speed of e.g. 70 and 50 km/h is more than two-fold (as shown in Figure 4.1). Especially in the early stages of AV deployment, incorporating safe driver behavior towards cyclists is expected to increase cyclist safety by actively avoiding accidents with cyclists.

Hypothesis 6 - Cyclist detection The majority of experts think cyclist detection by SAE-level 4 AVs will be better compared to human drivers. However, questions were raised about performance in adverse weather conditions. It was stated by many experts that sufficient cyclist detection is an important requirement for road safety between AVs and cyclists. This requirement is also assumed for the infrastructure readiness analysis. An important risk factor found to be problematic is a reduced visibility of a cyclists' trajectory path, increasing the challenge for AVs to accurately detect and classify cyclists. Although this does not necessarily lead to serious conflicts in all situations with reduced visibility, Situation Awareness is greatly reduced. Therefore, it is suggested that conflict situations with (partial) reduced visibility are adapted to better facilitate AVs. If an occluded situation could not be adjusted, the specific situation should not be included in the initial ODD.

Hypothesis 8 - Sensitivity/conservativeness As discussed previously at Hypothesis 5, experts expect AVs to behave more conservative compared to human drivers. If this conservative behavior is increased at specific high-risk situations, the severity of an accident decreases due to a lower vehicle speed. Resulting from the infrastructure readiness analysis, the specific high-risk situations can be identified.

Hypothesis 10 - Predictability in infrastructure Predictability of behavior is the Surrogate Measure of Safety mentioned most by experts, emphasizing the importance of predictable cyclist behavior. Mainly due to the difficult to predict cyclist behavior, physical segregation between AVs and cyclists on road sections was taken as a requirement for the infrastructure readiness analysis. By limiting exposure to cyclists only to intersections, continuous conflicts between AVs and cyclists are avoided. The Surrogate Measure of Safety 'predictability of behavior' is classified into different safety levels based on the infrastructure. The type of infrastructure at a conflict situation is considered to be very important for the predictability of cyclist behavior. If cyclists have priority, AVs have to yield for cyclists and cyclists will continue their path as they expect vehicles to yield. If an AV has priority, the risk of a cyclist doing something unpredictable always remains. If a situation is fully regulated by traffic lights, cyclist behavior will be better predictable, as cyclists have to yield in case of a red light. However, especially based on the design of a signalized intersection, cyclists sometimes violate the priority rules. It is expected that especially single-lane crossings facilitate cyclist violations, as the crossing distance is small.

Hypothesis 11 - Clear cycling infrastructure An accident risk factor frequently observed in the infrastructure readiness analysis, is missing road surface markings indicating a cyclist crossing. Infrastructure should be clear to improve Situation Awareness. It is suggested that these cyclist crossings are adjusted, such that AVs know where crossing cyclists can be expected.

Remaining hypotheses No findings of the infrastructure readiness analysis were related to the other hypotheses, meaning the remaining hypotheses are open for further research.

6.5.2 Infrastructure Adjustments in the Province of Noord-Holland

Of the 118 identified conflict situations in Section 6.4, 20 situations had at least one Surrogate Measure of Safety that was classified as a problem area. With minor (infrastructure) adjustments, road safety can be improved at the majority of these conflict situations. An overview of suggested adjustments per conflict situation is provided in Table 6.8. Three types of adjustments could improve safety at a total of 15 situations. Removing bushes is suggested to improve visibility of the cyclists' trajectory path in three situations. Adjusting road surface markings is suggested for two situations, changing situations with conflicting priority rules. The visibility at the N200 #1 is reduced due to a large tree, and it would require a major (and unnecessary) adjustment to remove this tree. As this situation is located at the beginning of the N200, it is suggested to exclude this situation from the initial ODD, and dispatch automated driving after this conflict situation. A similar suggestion is made for situation N200 #8, as the occlusion is caused by a small hill. As situations N200 #9 to #16 have multiple problems for multiple Surrogate Measures of Safety, it is suggested to fully exclude the N200 from the initial ODD from situation #8 onward. Furthermore, it is suggested to fully exclude the N206 from the initial ODD, as multiple road sections are present where cyclists are not physically segregated.

Table 6.8: Infrastructure adjustments to improve safety of problematic conflict situations in the province of Noord-Holland

Conflict situation	Google Street View link	Surrogate Measure of Safety	Problem	Adjustment
N197 #5	Link to N197 #5	Visibility	Occluded by bushes	Remove bushes
N200 #1	Link to N200 #1	Visibility	Occluded by a tree	Exclude from the ODD
N200 #8	Link to N200 #8	Visibility	Occluded by a small hill	Exclude from the ODD
N200 #9-16	Link to N200 #10 (e.g.)	*Multiple*	*Multiple*	Exclude from the ODD
N205 #1	Link to N205 #1	Visibility	Occluded by bushes	Remove bushes
N206	*Complete road*	*Multiple*	*Multiple*	Exclude from the ODD
N208 #10	Link to N208 #10	Visibility	Occluded by bushes	Remove bushes
N231 #24	Link to N231 #24	Infrastructure clarity	Conflicting priority rules	Adjust road surface markings
N232 #12	Link to N232 #12	Infrastructure clarity	Conflicting priority rules	Adjust road surface markings

Next to the conflict situations mentioned in Table 6.8, five other conflict situations had a Surrogate Measure of Safety that was classified as a problem area. In all these situations, visibility is partly reduced due to fences (i.e. N231 #23 and N232 #4, #5, #6 & #11). No adjustments are suggested, as these fences are mostly located on bridges. Together with OEMs, it should be determined if cyclist visibility is sufficient in these situations.

Minor infrastructure adjustments could also improve safety in many conflict situations where unclear infrastructure is classified as a ‘point of attention’. In nine situations, no road surface marking is present to indicate the possibility of crossing cyclists (i.e. N200 #5 & #7, N202 #2 & #3, N232 #16 & #17 and N243 #8, #12 & #13). Road surface markings should be provided at these situations. Furthermore, road surface markings are deteriorated and should be renewed at situations N231 #5 and N243 #11.

6.6 Conclusions

A methodology is presented to assess road safety of conflict situations between AVs and cyclists. Important requirements for the methodology to be used are physically segregated road sections (to avoid continuous conflicts) and sufficient cyclist detection (for AVs to be permitted on roads where cyclists can be encountered). Therefore, the methodology is applicable to junctions. Three different safety levels are distinguished for each Surrogate Measure of Safety, presented in a rubric.

The rubric is used to identify and assess conflict situations on provincial roads in Noord-Holland. Common identified accident risk factors are reduced visibility of the cyclist trajectory path, unclear road surface markings, and infrastructure facilitating visual communication and occasional cyclist traffic violations.

Road authorities can help improve road safety between AVs and cyclists by providing clear and predictable infrastructure, with good visibility of conflict situations and cyclists’ trajectory paths. Specifically for the Provincie Noord-Holland, conflicting priority rules should be adjusted, road surface markings should be provided where missing, and situations with reduced visibility should be adjusted.

Although some of the identified accident risk factors are also present for HDVs, these are considered to be a larger problem for AVs. This is based on the expected characteristics of AVs, e.g. having difficulty with visual communication and unknown infrastructure situations.

Highlights

- A rubric is presented (Table 6.1) to assess road safety between AVs and cyclists at junctions, distinguishing three different safety levels for each Surrogate Measure of Safety
- The rubric is used to assess safety of 118 conflict situations in the province of Noord-Holland
- Common accident risk factors identified in Noord-Holland are reduced cyclist visibility, unclear road surface markings, and infrastructure facilitating visual communication and occasional cyclist traffic violations
- Minor infrastructure adjustments (i.e. removing bushes, adjusting or providing road surface markings) could improve road safety between AVs and cyclists at many conflict situations in Noord-Holland

7 Discussion

This chapter presents discussion points related to this research. Before presenting the conclusions of this work, it is important to put things in perspective. Some limitations that influence the validity of the conclusions are also discussed. First, a reflection of the research methodology is given in Section 7.1 and a reflection of the results in Section 7.2. Some remaining research limitations are listed in Section 7.3. This chapter ends with an overview of the scientific and practical relevance of the presented work in Section 7.4.

7.1 Reflection of the Research Methodology

Subjective elements present The used research methodology has some subjective elements that could influence the results. To account for this, preventive measures were taken to limit the impact of subjectivity. Three important subjective elements are as follows.

Firstly, the statements given by experts result from their subjective view of Automated Vehicles (AVs). Based on their background and prior experience with cyclists and AVs, their opinion is formed. To diminish the subjective factor of expert interviews, experts with diverse backgrounds were chosen (i.e. from academic research parties, governmental bodies, and the cyclist industry), leading to different viewpoints. Furthermore, each expert was provided with exactly the same introduction of the study, including assumptions regarding SAE-level 4 AVs. As these AVs are not yet driving on Dutch roads, the interpretation of the exact capabilities of these vehicles was evaluated to be difficult by two experts.

Secondly, subjective elements are present in the interpretation of interview results leading to the classification of Surrogate Measures of Safety. This could be evaluated differently by another researcher. To clarify the process leading to the classification of Surrogate Measures of Safety, especially the qualitative interview results are discussed elaborately in Sections 5.3.2 and 5.3.3.

Thirdly, subjective elements are present in the safety assessment of conflict situations. A rubric with different safety levels for each Surrogate Measure of Safety is created. As most of the attributes are qualitatively described, there is room for subjectivity. To clarify the difference between the safety levels, an explanation of the attributes is provided, and examples of infrastructure situations are given. Additionally, no statements are made about conflict situations being sufficiently safe or not, only accident risk factors are mentioned. A next step for Original Equipment Manufacturers (OEMs) is to determine safety in an objective way by analyzing the conflict situations in more detail.

Qualitative assessment of safety Another important discussion point is the qualitative assessment of safety. Ideally, safety is determined in a quantitative way. However, as SAE-level 4 AVs do not yet drive on Dutch roads, this is not straightforward. Whereas there is much quantitative data available on road safety between cyclists and HDVs (Human Driven Vehicles), e.g. accident data, this is not available for AVs. Therefore, using Surrogate Measures of Safety is determined to be a valid alternative to assess road safety (e.g. based on Laureshyn et al. (2017); Johnsson et al. (2018)).

The different safety levels for most of the Surrogate Measures of Safety are described in a qualitative way for two reasons. First, quantitative data is not always available, such as for cyclist traffic volumes or the number of cyclist traffic violations. Second, it would require a study to determine the quantitative boundaries for each safety level in the rubric. The qualitative separation leads to a grey area for the differences between safety levels. It is, for example, difficult to determine whether a partly occluded cyclist trajectory path is a *'problem area'* or only a *'point of attention'*. To clarify the attributes for each Surrogate Measure of Safety, the infrastructure readiness analysis gives many examples of conflict situations with corresponding safety assessments. Appendix E provides an additional explanation for every attribute evaluated as a *'point of attention'* or *'problem area'*.

Furthermore, it is not determined if a conflict situation is considered to be sufficiently safe or not. This could be done in a quantitative way, for example by scoring the attributes for each Surrogate Measure of Safety (e.g. 0 for *'adequate'*, 1 for *'point of attention'*, and 3 for *'problem area'*. However, it was chosen to not score the attributes in this study as it would add an additional subjective element. Furthermore, equal importance of Surrogate Measures of Safety cannot be assumed.

Information on the relative importance of Surrogate Measures of Safety could be derived from Figure 5.6, based on how frequently each was mentioned in the expert interviews.

7.2 Reflection of the Results

It is important to mention that the results are influenced by the presence of subjective and qualitative elements, as discussed in Section 7.1. Some other discussion points for the results are discussed here.

Operational Design Domain The results of this study can function as input to determine which accident risk factors significantly decrease cyclist safety, and situations with these risks can be excluded from the initial Operational Design Domain (ODD). This decision will be made by the OEMs, who first have to prove their AVs can safely drive in the specified ODD. This means that safety needs to be on-board instead of being dependent on infrastructure. Therefore, the results are not meant to lead to drastic infrastructure changes to better accommodate AVs. It is for example not advised to change priority rules, as that will lead to dangerous situations for other road users. However, certain infrastructure changes can facilitate the use of AVs on provincial roads. There is a role for road authorities (such as the Provincie Noord-Holland) to aid in increasing Situation Awareness of AVs. This can, for example, be done by providing clear road surface markings, good visibility of conflict situations, and intelligent traffic lights.

Another suggestion for road authorities is to aid in providing possibilities for minimal risk conditions. It is assumed that a human driver takes over outside the ODD. If not, the AV will bring itself in a minimal risk condition. Road authorities could better facilitate minimal risk conditions by providing hard shoulders[7] at the boundaries of the defined ODD. Currently, these hard shoulders are already present at specific locations alongside provincial roads.

Dutch cycling environment It is essential to realize that this study focuses on the Dutch cycling environment, which is highly unique compared to other countries. The results (e.g. defined Surrogate Measures of Safety or the rubric to assess road safety) are therefore mainly applicable to Dutch situations. When translating the results to other countries, it is important to take into account the differences in cycling environment. These differences can be based on road infrastructure and cycling behavior. A type of cycling behavior that is only common in the Netherlands is, for example, cycling next to each other. Although identified accident risk factors can be similar in other countries, the differences in cycling behavior can lead to a different assessment of safety. However, it is expected that if AVs can safely drive in the complex cycling environment in the Netherlands, this would be the same for less complex environments in other countries.

Unknown accident risk factors The results are based on accident risk factors that can be determined based on the information that is present. However, it is probable that there will be other risk factors for AVs and cyclists that are currently yet unknown. An example of unexpected behavior of AVs is observed for the Tesla-update with stop sign recognition. When driving past a Burger King sign, a Tesla identified the sign as a stop sign and decelerated accordingly.[8] It is important to prepare AVs for known situations, but certainly, it is also important to be able to safely deal with yet unknown situations. This is related to the statement of Botello et al. (2019), saying that detection systems must not rely on built environment characteristics to determine where cyclists can be expected. Although the probability is significantly lower, in reality, cyclists can be encountered at other locations than the identified conflict situations.

7.3 Research Limitations

Next to the discussion points related to the methodology and results, there are some other limitations of the presented work:

- Cyclist detection and classification algorithms might be better than what is assumed in this research based on scientific literature. However, detailed information from OEMs is not publicly available and could therefore not be studied.

[7] In Dutch: *'pechhaven'* or *'vluchthaven'*

[8] Tesla Autopilot identified a Burger King sign as a stop sign: `https://youtu.be/jheBC0pE9ws`

- No experts from OEMs were interviewed. To account for this, experts with prior experience with AVs were contacted.
- Cyclist traffic volumes were not taken into account for the infrastructure readiness analysis, as detailed data were not available for the majority of conflict situations. However, as discussed, cyclist traffic volume is not expected to significantly affect safety due to AVs continuously monitoring the environment in 360 degrees.
- The infrastructure readiness analysis does not take into account the complete provincial road network in Noord-Holland. Therefore, it might be that the results are not representative for the remainder of the roads, and other accident risk factors could be present that are not identified. This is partly accounted for by analyzing multiple roads for each traffic management quality level, to obtain a diversity of conflict types.
- No distinction is made between conventional bikes and e-bikes. More and more e-bikes are appearing on Dutch roads, and cyclist behavior on e-bikes might differ significantly from conventional cyclists. For example, higher speeds are observed and many elderly use e-bikes. Therefore, it might be valuable if AVs could classify e-bikes as a separate cyclist type.

7.4 Contributions of the Presented Research

This study aims to contribute to creating additional attention for cyclist safety when further developing AVs. The following scientific and practical contributions are provided:

Scientific contributions

- **Overview of determinants affecting road safety between AVs and cyclists** - There is a lack of scientific research focusing on road safety between AVs and cyclists. The literature review provides an elaborate overview of determinants that are found to affect road safety when AVs and cyclists are to interact. Together, these determinants describe the complex cycling environment present in the Netherlands. The determinants give an overview of the important factors affecting cyclist safety, both positively and negatively. Furthermore, the formulated hypotheses to promote road safety between AVs and cyclists are not all dealt with in this study. Therefore, multiple hypotheses are still to be explored in further research.
- **Methodology to assess road safety between AVs and cyclists** - As SAE-level 4 AVs and cyclists do not yet share the road, at least not in the complex cycling environment in the Netherlands, determining the safety level is not straightforward. The methodology used in this study was found to be useful to objectify road safety between AVs and cyclists. The identified Surrogate Measures of Safety could be used in further research to more accurately determine the implications of each measure for cyclist safety. Additionally, the approach of interviewing experts was found to be valuable for identifying important risk factors for a scenario that does not yet exist. Furthermore, the rubric providing a classification of the Surrogate Measures of Safety is made such that it can be used in other studies. The rubric can be used to identify accident risk factors at specific conflict situations, or for complete road networks.

Practical contributions

- The rubric to assess road safety can be used by road authorities to analyze the infrastructure readiness of their road network for a safe interaction between AVs and cyclists. Based on the rubric, accident risk factors could be identified to determine problematic conflict situations.
- The risk factors for cyclist safety can be used as input for OEMs to determine their focus points. To guarantee cyclist safety when AVs operate in mixed traffic environments, safety on-board of AVs should minimize these risks.
- Specific conflict situations in the province of Noord-Holland could be adjusted based on the suggested infrastructure adjustments. Certain minor infrastructure adjustments could improve road safety between AVs and cyclists at many conflict situations in Noord-Holland. Furthermore, the results could be taken into account for the design of new infrastructure projects, thereby promoting road safety between AVs and cyclists.

8 Conclusions and Recommendations

By replacing human drivers, Automated Vehicles (AVs) have a large potential to increase road safety. However, the great number of cyclists in the Netherlands contributes significantly to creating a challenging environment for AVs. Challenges for AVs are present for e.g. cyclist detection, classification, and trajectory prediction. To maintain the favorable position of cyclists in the Netherlands, it is important that the presence of AVs does not result in a decrease in cyclist safety. The main research question of this research was:
How to promote road safety between SAE-level 4 Automated Vehicles and cyclists in mixed traffic environments outside city limits?

The results of this study are aimed to be a starting point towards additional attention for cyclists during the development of AVs. The objective of this study is to promote road safety between AVs and cyclists, by adding the following contributions:

- Presenting a methodology to assess road safety between AVs and cyclists (Section 8.1)
- Identifying accident risk factors on the existing road network in the province of Noord-Holland (Section 8.2)
- Providing focus points for future research to promote road safety between AVs and cyclist (Section 8.3)

8.1 Methodology to Assess Road Safety Between Automated Vehicles and Cyclists

As SAE-level 4 AVs and cyclists do not yet share the road, at least not in the complex cycling environment in the Netherlands, determining the safety level is not straightforward. Therefore, Surrogate Measures of Safety are identified to objectify road safety. Based on these Surrogate Measures of Safety, a methodology is presented to assess road safety of conflict situations between AVs and cyclists. The methodology, presented in a rubric in Table 8.1, distinguishes three different safety levels for each Surrogate Measure of Safety. The rubric was found to be useful to objectify road safety between AVs and cyclists, and to identify accident risk factors at conflict situations.

Table 8.1: Classification of Surrogate Measures of Safety to assess road safety at junctions

Surrogate Measure of Safety*	**Adequate**	**Point of attention**	**Problem area**
Vehicle speed	<50 km/h	50 – 80 km/h	>80 km/h
Cyclist traffic volume	Low; Medium	High	
Predictability of behavior	Signalized intersection; Priority intersection (cyclists having priority)	Priority intersection (AVs having priority)	Non-priority intersection; Shared space
Visibility	Clear overview of conflict situation and cyclist trajectory path	Conflict situation or cyclist trajectory path could be (partly) occluded	Conflict situation or cyclist trajectory path (partly) occluded
Infrastructure clarity	Good quality of road surface markings and situation is according to CROW guidelines	Deteriorated quality of road surface markings or missing road signs	Situation is not according to CROW guidelines; No standard (trained) situation
Visual communication required	Seldom: design of infrastructure does not facilitate visual communication	Sometimes: design of infrastructure facilitates visual communication in certain specific scenarios	Often: purpose of infrastructure is to communicate
Cyclist traffic violations	Seldom: infrastructure facilitates almost no violations	Sometimes: infrastructure facilitates occasional violations	Often: infrastructure facilitates violations (consciously or unconsciously)

**Degree of segregation and cyclist detection accuracy are not included, as these are taken as a requirement for road safety: road sections must be physically segregated and cyclists need to be accurately detected and classified by AVs*

It is important to mention that the results of the methodology cannot be used to determine if conflict situations are sufficiently safe for AVs to be permitted at these situations. Two important requirements are assumed for the methodology to be used. First, cyclists and AVs should be physically segregated at road sections to avoid continuous conflicts. Second, cyclist detection capabilities of AVs should be sufficient for AVs to be permitted on roads where cyclists can be encountered. Therefore, the rubric can be used to assess road safety of junctions.

Furthermore, it needs to be noted that this study focuses on the cycling environment in the Netherlands, which is highly unique compared to other countries. The methodology is therefore primarily applicable to situations in the Netherlands. When using the methodology in other countries, it is important to take into account the differences in cycling environment. These differences can be based on road infrastructure and cycling behavior. Although identified accident risk factors can be similar in other countries, the differences in cycling behavior can lead to a different assessment of safety.

8.2 Identified Accident Risk Factors

The presented methodology is demonstrated for a case-study in the province of Noord-Holland, analyzing 163.5 *km* of road with a total of 118 conflict situations for AVs and cyclists. Accident risk factors on provincial roads in Noord-Holland are identified. Common risk factors are reduced visibility of the cyclists' trajectory path, unclear infrastructure due to missing road surface markings, and infrastructure facilitating visual communication and occasional cyclist traffic violations.

The results of the case-study can function as input for Original Equipment Manufacturers (OEMs) to determine which accident risk factors lead to a significant decrease in cyclist safety. A next step for OEMs is to prove their AVs can safely drive at the identified conflict situations. The decision if a conflict situation should be included in the Operational Design Domain (ODD) should be made by the OEMs. Although safety primarily needs to be on-board of AVs, road authorities can improve road safety e.g. by providing clear and predictable infrastructure, with good visibility of conflict situations and cyclists' trajectory paths.

In the province of Noord-Holland, minor infrastructure adjustments can improve road safety at many of the identified conflict situations. Removing bushes at certain situations is suggested to improve visibility of the cyclists' trajectory path. Furthermore, adjusting road surface markings is suggested for situations with conflicting priority rules or deteriorated quality of road infrastructure. Finally, it is suggested to provide road surface markings at situations where no road surface marking is present to indicate the possibility of crossing cyclists.

Based on the identified accident risk factors, methods are suggested to minimize these risks and thus promote road safety. An overview of the most important findings to promote road safety between AVs and cyclists is presented in Table 8.2 for each Surrogate Measure of Safety.

Table 8.2: Methods to promote road safety between Automated Vehicles and cyclists

Surrogate Measure of Safety	**Methods to promote road safety**
Degree of segregation	Continuous conflicts should be avoided, therefore cyclists should be physically segregated from AVs at road sections
Vehicle speed	Lowering vehicle speeds at conflict situations where cyclists could be encountered, ensures a reduced cyclist fatality rate in case of an accident due to lower impact speeds
Cyclist traffic volume	Collecting cyclist traffic volume data gives more insight in which junctions have a large exposure
Predictability of behavior	Signalized intersections are preferred due to the regulated situation. Intelligent traffic lights should be used to communicate with AVs, and intersections with increased risk should be identified e.g. based on cyclists' red-light running numbers.
Visibility	Conflict situations with a (partly) occluded cyclists' trajectory path should be adjusted or excluded from the initial ODD
Infrastructure clarity	Infrastructure should be according to CROW guidelines to ensure recognizability, and road surface markings should be present at locations where cyclists could cross to increase Situation Awareness
Visual communication required	More knowledge of the exact implications for cyclist safety is needed for the specific interaction scenarios where visual communication is facilitated
Cyclist detection accuracy	Before AVs are permitted to drive in mixed traffic environments, cyclist detection accuracy should be sufficient
Cyclist traffic violations	More knowledge of the exact implications for cyclist safety is needed for the specific interaction scenarios where cyclist traffic violations are facilitated

8.3 Recommendations for Future Research

This research aims to be a starting point towards more attention for cyclists during the development of AVs. The results of the current work present an overview of accident risk factors that should be taken into account, either from the perspective of the AV or the road infrastructure. However, much work has to be done in order to further promote safety between AVs and cyclists. Based on the limitations of this work and the needs for promoting road safety, some recommendations for future research are as follows:

- **Improve Situation Awareness towards cyclists**
  Currently, AV technology is considered to be not yet sufficiently advanced in terms of detection capabilities. One of the requirements for a safe interaction is that all three levels of Situation Awareness should be correct: i.e. cyclist detection, classification, and trajectory prediction. Future research should focus on developing AV technology to improve the detection and classification of cyclists. It is important to guarantee accurate detection in many diverse situations, such as in adverse weather conditions, during darkness, and with sun glare. The Dutch Vehicle Authority (RDW) must formulate requirements on how to determine whether an AV is sufficiently safe to be permitted in mixed traffic environments.

  Another research direction to improve Situation Awareness is understanding cyclist behavior, which is essential for correct trajectory prediction. More information on the behavioral adaptation of cyclists towards AVs is desired, as the exact implications are yet unknown. Additionally, understanding the differences in behavior based on cyclist type can be useful. If the differences in the behavior of different cyclist types are better known, this can be used in supervised learning for AV algorithms to improve trajectory prediction.

  Improving Situation Awareness also goes the other way around: research to come up with reliable and understandable External Human Machine Interfaces should continue, to communicate the intentions of AVs to cyclists.

- **Analyze problematic scenarios in more detail**
  The presented accident risk factors and problematic scenarios are based on subjective and qualitative assessment of the Surrogate Measures of Safety. An important next step is to quantify the safety levels, to be able to objectively determine whether a conflict situation is sufficiently safe or not. Certain scenarios need to be analyzed in more detail, including but not limited to:

  – Situations with reduced visibility, to determine the implications for cyclist detection
  – Situations facilitating visual communication, to understand the challenges of informal behavior, e.g. at roundabouts where cyclists do not have priority
  – Situations facilitating cyclist violations, to determine the severity of these violations, e.g. at single-lane crossings and roundabouts where cyclist do not have priority
  – Situations with unclear road surface markings, to determine if changes are needed

  It is important that all aspects of road safety are taken into account, e.g. from the perspective of cyclists, AVs and the road infrastructure. Therefore, collaboration between road authorities, Original Equipment Manufacturers (OEMs), and the cycling industry is preferred.

- **Train Automated Vehicles in specific Dutch situations**
  Multiple accident risk factors and problematic infrastructure situations are presented in this research. However, this does not necessarily mean the risks are too large for safe interaction. Unfortunately, accidents will happen in traffic. A future research direction for OEMs is to prove their AVs are able to cope with the risks in a safe way. Therefore, it is important that AVs are trained in situations with cyclists. As the Dutch cycling environment is significantly different from other countries, it is evident that AVs are trained in specific Dutch situations. In the province of Noord-Holland, pilots can be held on specific roads based on the results of the infrastructure readiness analysis. Road sections can be selected based on the type of conflict situations and their present attributes for each Surrogate Measure of Safety. During these pilots, it is essential that the safety of other road users is ensured. This highlights the importance of collaboration between road authorities and OEMs.

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A Levels of Driving Automation

The term 'Automated Vehicle' can refer to different types of vehicle automation, an overview of which is provided in this appendix. The classification of SAE International is widely used, distinguishing six different driving automation levels, ranging from 'No Driving Automation' to 'Full Driving Automation'. An overview of the different levels and corresponding characteristics is presented in Figure A.1. More information on the different levels can be found in SAE International (2018). As discussed in Section 1.2, this study focuses on 'High Driving Automation, also referred to as SAE-level 4 Automated Vehicles.

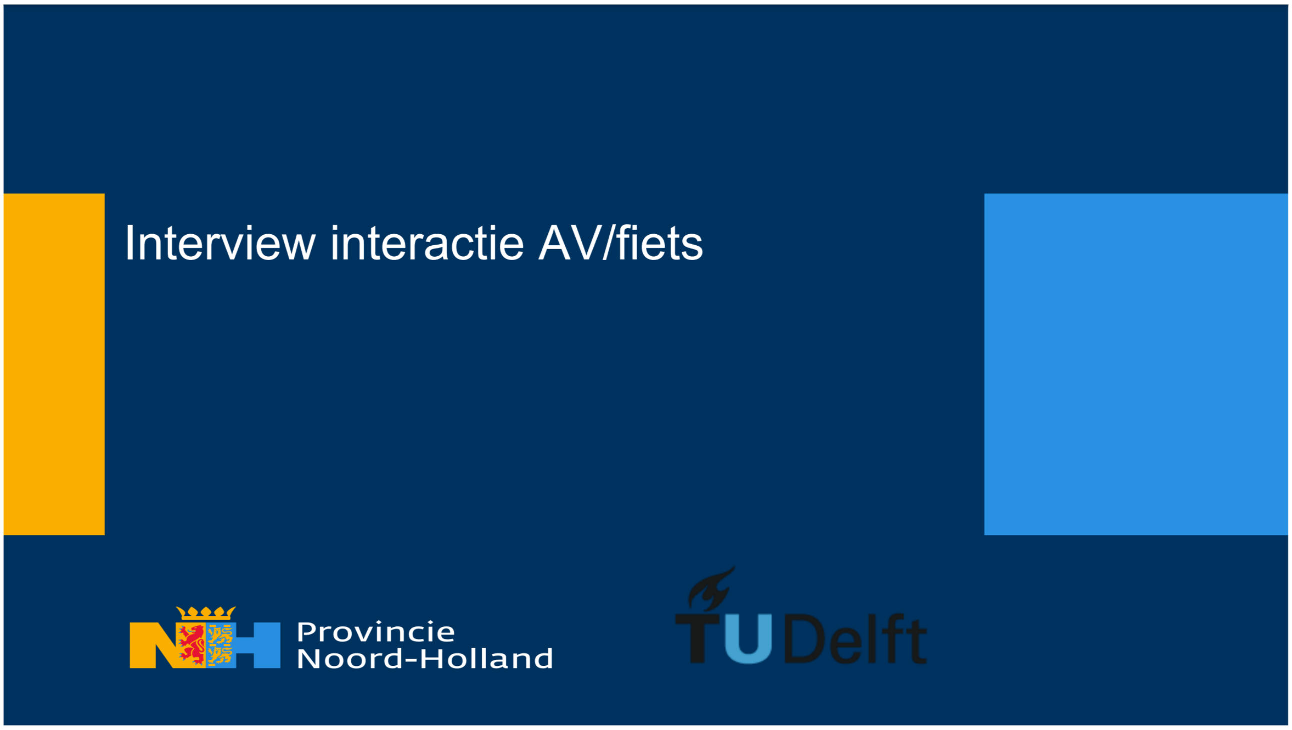
An overview of the abbreviations used and their meaning is as follows:

- DDT = Dynamic Driving Task
- OEDR = Object and Event Detection and Response
- ODD = Operational Design Domain
- ADS = Automated Driving System

Level	Name	Narrative definition	*DDT*: *Sustained lateral and longitudinal vehicle motion control*	*DDT*: *OEDR*	*DDT fallback*	*ODD*
Driver* performs part or all of the *DDT						
0	No Driving Automation	The performance by the *driver* of the entire *DDT*, even when enhanced by *active safety systems*.	*Driver*	*Driver*	*Driver*	n/a
1	Driver Assistance	The *sustained* and *ODD*-specific execution by a *driving automation system* of either the *lateral* or the *longitudinal vehicle motion control* subtask of the DDT (but not both simultaneously) with the expectation that the *driver* performs the remainder of the *DDT*.	*Driver* and *System*	*Driver*	*Driver*	Limited
2	Partial Driving Automation	The *sustained* and *ODD*-specific execution by a *driving automation system* of both the *lateral* and *longitudinal vehicle motion control* subtasks of the *DDT* with the expectation that the *driver* completes the *OEDR* subtask and *supervises* the *driving automation system*.	***System***	*Driver*	*Driver*	Limited
***ADS* ("*System*") performs the entire *DDT* (while engaged)**						
3	Conditional Driving Automation	The *sustained* and *ODD*-specific performance by an *ADS* of the entire DDT with the expectation that the *DDT fallback-ready user* is *receptive* to *ADS*-issued *requests to intervene*, as well as to *DDT performance-relevant system failures* in other *vehicle* systems, and will respond appropriately.	*System*	***System***	*Fallback-ready user (becomes the driver during fallback)*	Limited
4	High Driving Automation	The *sustained* and *ODD*-specific performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	***System***	Limited
5	Full Driving Automation	The *sustained* and unconditional (i.e., not *ODD*-specific) performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	*System*	**Unlimited**

Figure A.1: Levels of driving automation according to the classification of the Society of Automotive Engineers (SAE International, 2018)

B Interview Questions



Introductie

- MSc. thesis TU Delft in samenwerking met Provincie Noord Holland
- Interactie tussen zelfrijdende voertuigen (AVs) en fietsers
- Analyse van geschiktheid van verschillende typen infrastructuur
- Focus op verkeersveiligheid voor fietsers
- Situatie in Nederland

Definitie Automated Vehicles (AVs)

- Level 4: highly automated
- Volledig zelfrijdend binnen een gelimiteerd gebied: ODD (Operational Design Domain)
- Bestuurder in de auto aanwezig om over te nemen buiten het gebied
- Onbekende situatie? Bestuurder neemt over, of AV brengt zichzelf in veiligheid

Opzet

- 3 achtergrondvragen
- 1 testsituatie
- 9 infrastructuur situaties
- Top-3 meest (on)veilige situaties

Hoe vaak fietst u? (voor Corona)

○ Dagelijks (6-7x per week)
○ 2-5x per week
○ 1x per week
○ 1x per maand
○ <1x per maand

In hoeverre bent u bekend met zelfrijdende voertuigen?

- o Zeer bekend
- o Bekend
- o Redelijk bekend
- o Enigszins bekend
- o Niet bekend

In hoeverre heeft u vertrouwen in de technologie van zelfrijdende voertuigen?

	1	2	3	4	5	
Zeer weinig vertrouwen	○	○	○	○	○	Zeer veel vertrouwen

30

Test situatie: Fietsstraat

1. Gelet op de verkeersveiligheid voor fietsers, hoe complex vindt u deze situatie voor zelfrijdende voertuigen?

Niet complex voor AV: Verkeersveiligheid omhoog		Neutraal		Te complex voor AV: Verkeersveiligheid omlaag
○	○	○	○	○
1	2	3	4	5

2. Wat zijn hiervoor uw redenen?
   Open vraag

3. Als zelfrijdende voertuigen op de openbare weg gaan rondrijden:
   Zou u deze situatie wel of niet toevoegen aan het Operational Design Domain (ODD)?
   Wel / niet

70

Situatie 1: Verkeerslichten

1. Gelet op de verkeersveiligheid voor fietsers, hoe complex vindt u deze situatie voor zelfrijdende voertuigen?

Niet complex voor AV: Verkeersveiligheid omhoog		Neutraal		Te complex voor AV: Verkeersveiligheid omlaag
○ 1	○ 2	○ 3	○ 4	○ 5

2. Wat zijn hiervoor uw redenen?

3. Als zelfrijdende voertuigen op de openbare weg gaan rondrijden: Zou u deze situatie wel of niet toevoegen aan het Operational Design Domain (ODD) van zelfrijdende voertuigen?

Situatie 2: Verkeerslichten (deelconflict)

1. Gelet op de verkeersveiligheid voor fietsers, hoe complex vindt u deze situatie voor zelfrijdende voertuigen?

Niet complex voor AV: Verkeersveiligheid omhoog		Neutraal		Te complex voor AV: Verkeersveiligheid omlaag
○ 1	○ 2	○ 3	○ 4	○ 5

2. Wat zijn hiervoor uw redenen?

3. Als zelfrijdende voertuigen op de openbare weg gaan rondrijden: Zou u deze situatie wel of niet toevoegen aan het Operational Design Domain (ODD) van zelfrijdende voertuigen?

60

Situatie 3: Voorrangskruispunt (dwarsongeval)

1. Gelet op de verkeersveiligheid voor fietsers, hoe complex vindt u deze situatie voor zelfrijdende voertuigen?

Niet complex voor AV: Verkeersveiligheid omhoog		Neutraal		Te complex voor AV: Verkeersveiligheid omlaag
○ 1	○ 2	○ 3	○ 4	○ 5

2. Wat zijn hiervoor uw redenen?

3. Als zelfrijdende voertuigen op de openbare weg gaan rondrijden: Zou u deze situatie wel of niet toevoegen aan het Operational Design Domain (ODD) van zelfrijdende voertuigen?

80

Situatie 4: Voorrangskruispunt (langsongeval)

1. Gelet op de verkeersveiligheid voor fietsers, hoe complex vindt u deze situatie voor zelfrijdende voertuigen?

Niet complex voor AV: Verkeersveiligheid omhoog		Neutraal		Te complex voor AV: Verkeersveiligheid omlaag
○ 1	○ 2	○ 3	○ 4	○ 5

2. Wat zijn hiervoor uw redenen?

3. Als zelfrijdende voertuigen op de openbare weg gaan rondrijden:
Zou u deze situatie wel of niet toevoegen aan het Operational Design Domain (ODD) van zelfrijdende voertuigen?

Situatie 5: Rotonde (fietsers uit de voorrang)

1. Gelet op de verkeersveiligheid voor fietsers, hoe complex vindt u deze situatie voor zelfrijdende voertuigen?

Niet complex voor AV: Verkeersveiligheid omhoog		Neutraal		Te complex voor AV: Verkeersveiligheid omlaag
○ 1	○ 2	○ 3	○ 4	○ 5

2. Wat zijn hiervoor uw redenen?

3. Als zelfrijdende voertuigen op de openbare weg gaan rondrijden:
Zou u deze situatie wel of niet toevoegen aan het Operational Design Domain (ODD) van zelfrijdende voertuigen?

Situatie 6: Rotonde (fietsers in de voorrang)

1. Gelet op de verkeersveiligheid voor fietsers, hoe complex vindt u deze situatie voor zelfrijdende voertuigen?

Niet complex voor AV: Verkeersveiligheid omhoog		Neutraal		Te complex voor AV: Verkeersveiligheid omlaag
○ 1	○ 2	○ 3	○ 4	○ 5

2. Wat zijn hiervoor uw redenen?

3. Als zelfrijdende voertuigen op de openbare weg gaan rondrijden:
Zou u deze situatie wel of niet toevoegen aan het Operational Design Domain (ODD) van zelfrijdende voertuigen?

60

Situatie 7: Erftoegangsweg

1. Gelet op de verkeersveiligheid voor fietsers, hoe complex vindt u deze situatie voor zelfrijdende voertuigen?

Niet complex voor AV: Verkeersveiligheid omhoog		Neutraal		Te complex voor AV: Verkeersveiligheid omlaag
○ 1	○ 2	○ 3	○ 4	○ 5

2. Wat zijn hiervoor uw redenen?

3. Als zelfrijdende voertuigen op de openbare weg gaan rondrijden:
Zou u deze situatie wel of niet toevoegen aan het Operational Design Domain (ODD) van zelfrijdende voertuigen?

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Situatie 8: Erftoegangsweg met fietssuggestiestrook

1. Gelet op de verkeersveiligheid voor fietsers, hoe complex vindt u deze situatie voor zelfrijdende voertuigen?

Niet complex voor AV: Verkeersveiligheid omhoog		Neutraal		Te complex voor AV: Verkeersveiligheid omlaag
○ 1	○ 2	○ 3	○ 4	○ 5

2. Wat zijn hiervoor uw redenen?

3. Als zelfrijdende voertuigen op de openbare weg gaan rondrijden:
Zou u deze situatie wel of niet toevoegen aan het Operational Design Domain (ODD) van zelfrijdende voertuigen?

50

Situatie 9: Fietsstrook

1. Gelet op de verkeersveiligheid voor fietsers, hoe complex vindt u deze situatie voor zelfrijdende voertuigen?

Niet complex voor AV: Verkeersveiligheid omhoog		Neutraal		Te complex voor AV: Verkeersveiligheid omlaag
○ 1	○ 2	○ 3	○ 4	○ 5

2. Wat zijn hiervoor uw redenen?

3. Als zelfrijdende voertuigen op de openbare weg gaan rondrijden:
Zou u deze situatie wel of niet toevoegen aan het Operational Design Domain (ODD) van zelfrijdende voertuigen?

Top 3 meest veilige situaties voor AVs en fietsers

Situatie 1: Verkeerslichten
Situatie 2: Verkeerslichten (deelconflict)
Situatie 3: Voorrangskruispunt (dwarsongeval)
Situatie 4: Voorrangskruispunt (langsongeval)
Situatie 5: Rotonde (fietsers uit de voorrang)
Situatie 6: Rotonde (fietsers in de voorrang)
Situatie 7: Erftoegangsweg
Situatie 8: Erftoegangsweg met fietssuggestiestrook
Situatie 9: Fietsstrook

Top 3 meest onveilige situaties voor AVs en fietsers

Situatie 1: Verkeerslichten
Situatie 2: Verkeerslichten (deelconflict)
Situatie 3: Voorrangskruispunt (dwarsongeval)
Situatie 4: Voorrangskruispunt (langsongeval)
Situatie 5: Rotonde (fietsers uit de voorrang)
Situatie 6: Rotonde (fietsers in de voorrang)
Situatie 7: Erftoegangsweg
Situatie 8: Erftoegangsweg met fietssuggestiestrook
Situatie 9: Fietsstrook

Verdere op/aanmerkingen?

C Expert Statements

This appendix provides an overview of statements made by experts during the interviews. Each statement is categorized into one of the predefined Surrogate Measures of Safety. If not directly related, a statement is classified as *'other'*. Table C.1 gives an overview of the number of times a Surrogate Measure of Safety is mentioned for each specific situation. As the number of experts interviewed was eleven, this is the highest possible number of mentions. The statements are provided for each cell in Figure C.1. If a statement was related to multiple Surrogate Measures of Safety, it is mentioned (and counted) multiple times. Furthermore, multiple statements per expert can be found for a single Surrogate Measure of Safety. If multiple statements related to the single Surrogate Measure of Safety were mentioned subsequently, it is included as one statement. If it was separated by a statement related to another Surrogate Measure of Safety, it is included as multiple statements. Sometimes, a statement was made after answering a question about a specific Surrogate Measure of Safety. In that case, the statement is not counted in Figure C.1.

Surrogate Measure of Safety	1. Signalized intersection	2. Signalized intersection (permitted conflict)	3. Priority intersection (cross traffic)	4. Priority intersection (through traffic)	5. Roundabout (cyclists having no priority)	6. Roundabout (cyclists having priority)	7. Access road	8. Access road (with advisory bicycle lanes)	9. Bicycle lane	Total
Degree of segregation	4	1	2	0	0	0	5	8	8	28
Vehicle speed	3	1	6	2	5	4	7	2	2	32
Cyclist traffic volume	0	1	0	2	2	1	6	5	1	18
Predictability of behavior	10	8	5	6	7	11	3	5	6	61
Visibility	1	1	7	6	3	2	1	0	2	23
Infrastructure clarity	1	3	2	1	1	3	1	6	1	19
Visual communication required	0	0	2	1	4	2	1	1	1	12
Cyclist detection accuracy	5	9	3	8	5	5	5	2	2	44
Cyclist traffic violations	9	2	7	0	8	1	0	0	2	29
Other	5	6	4	6	3	4	7	7	0	42

Figure C.1: Number of times a Surrogate Measure of Safety is mentioned for each specific situation (N=11)

C.1 Situation 1 - Signalized intersection

Degree of segregation - mentioned by 4 experts

Expert 1: Niet ongelijkvloers, dus blijft een risico dat een fiets denkt slimmer te zijn dan een verkeerslicht
Expert 3: Gescheiden remweg, fietsers zijn gescheiden van de rijbaan
Expert 10: Links en rechts een opstelstrook voor fietsers. Ook een stoplicht voor fietsers, dan is dat geen enkel issue.
Expert 11: Alles gescheiden
Expert 11: Gescheiden fietsinfrastructuur, wat ook niet altijd het geval is

Vehicle speed - mentioned by 3 experts

Expert 1: blijft een risico als AV hier met 80 aankomt en er een fietser door rood gaat: dan is de kans op aanrijding groot.
Expert 4: En dat er iets gedaan wordt aan de snelheid waarmee AV het kruispunt nadert, om eventuele roodlichtnegatie van fietsers zo goed mogelijk te kunnen corrigeren.
Expert 5: Wat het enige onveilige hier zou zijn, is onverwacht gedrag van een fietser. Bijvoorbeeld door rood rijden. Ook gezien de snelheid van het voertuig

Cyclist traffic volume - mentioned by 0 experts

Predictability of behavior - mentioned by 10 experts
Expert 1: Voorspelbare situatie
Expert 2: AV zal niet door rood rijden, of de kans is in ieder geval aanmerkelijk kleiner. Dat zijn nu de grootste klappers, met auto's die door rood rijden.
Expert 3: Volledig gereguleerd door de verkeerslichten
Expert 4: Wel opletten op fietsers die onverwacht toch oversteken
Expert 5: Heel duidelijk wat er van een AV wordt verwacht, Duidelijk wat voor gedrag een AV kan verwachten van een fietser,
Expert 5: Wat het enige onveilige hier zou zijn, is onverwacht gedrag van een fietser. Bijvoorbeeld door rood rijden.
Expert 7: Hierbij gaat de verkeersveiligheid toch enigszins omhoog, omdat het situaties met doorrijden van voertuigen zou moeten afnemen. Ik verwacht minder voertuigen die nog net oranje of rood meepakken, en dat is een gevaarlijke situatie voor fietsers. Geredeneerd vanuit het voertuig: ik denk dat dat met level 4 voertuigen zich niet zal voordoen.
Expert 8: Redelijk standaardsituatie met weinig onverwachte bewegingen en situaties, zowel van fietsers als auto's
Expert 9: Volledig gereguleerd
Expert 10: Links en rechts een opstelstrook voor fietsers. Ook een stoplicht voor fietsers, dan is dat geen enkel issue
Expert 11: Gereguleerd met verkeerslichten

Visual communication required - mentioned by 0 experts

Visibility - mentioned by 1 expert
Expert 11: Heel overzichtelijk

Infrastructure clarity - mentioned by 1 expert
Expert 4: Gewoon rechtdoor en lijntjes volgen

Cyclist detection accuracy - mentioned by 5 experts
Expert 5: AV heeft geen last van afleiding, dus zal die een fietser sneller herkennen bij een overtreding, en kan daar sneller op reageren.
Expert 6: Afhankelijk van de situatie buiten: in daglicht zal een AV beter reageren op fietser. In minder goed licht, dan moet ik nog zien dat we de technologie zo ver krijgen dat het beter wordt
Expert 7: Ervan uitgaande dat level 4 voertuig in staat is om op deze afstand fietsers te herkennen, zou de verkeersveiligheid licht omhoog moeten gaan.
Expert 9: Alleen toevoegen aan ODD als die ook in staat is om de fietser die door rood rijdt te detecteren
Expert 10: AVs kunnen heel snel zien of iemand een intentie heeft om door te rijden of door rood te rijden, dus dat is geen enkel probleem

Cyclist traffic violations - mentioned by 9 experts
Expert 1: AV kan misschien wel beter omgaan met roodlichtnegatie van fietser, maar blijft een risico als AV hier met 80 aankomt en er een fietser door rood gaat: dan is de kans op aanrijding groot.
Expert 2: Dit kruispunt is grootschalig, waardoor de fietser niet snel door het rode licht zal rijden. De vraag is wel hoe de AV is afgesteld. Als ze toch stoppen als een fietser door rood rijdt, krijg je misschien andere onveilige situaties.
Expert 4: En dat er iets gedaan wordt aan de snelheid waarmee AV het kruispunt nadert, om eventuele roodlichtnegatie van fietsers zo goed mogelijk te kunnen corrigeren.
Expert 4: Wel opletten op fietsers die onverwacht toch oversteken
Expert 5: Wat het enige onveilige hier zou zijn, is onverwacht gedrag van een fietser. Bijvoorbeeld door rood rijden.
Expert 5: AV heeft geen last van afleiding, dus zal die een fietser sneller herkennen bij een overtreding, en kan daar sneller op reageren.
Expert 6: je zit nog steeds met verkeer wat door rood gaat rijden, zowel auto's als fietsers
Expert 7: Fietsers nog even snel oversteken als ze geen groen hebben: daar zou een level 4 voertuig ook goed mee uit de

voeten kunnen.
Expert 9: Als er een fietser door rood rijdt, dan verwacht ik dat een AV dat wel oppakt. Dat zou wel een risico kunnen zijn
Expert 9: Alleen toevoegen aan ODD als die ook in staat is om de fietser die door rood rijdt te detecteren
Expert 10: AVs kunnen heel snel zien of iemand een intentie heeft om door te rijden of door rood te rijden, dus dat is geen enkel probleem
Expert 11: *Mentioned during questioning at situation 3:* De enige twijfel zit hem dus in het geval dat zo'n fietser de voorrang negeert en wel gewoon oversteekt. Maar dat geldt ook voor de eerste situatie, als een fietser het rode licht negeert. Dan heb je het zelfde probleem als hier eigenlijk. Hier is het misschien nog wat onoverzichtelijker, en dan moet zo'n auto gewoon ingrijpen.

Other - 5 arguments given
Expert 2: *Sensitivity/conservativeness* - De vraag is wel hoe de AV is afgesteld. Als ze toch stoppen als een fietser door rood rijdt, krijg je misschien andere onveilige situaties.
Expert 4: *Communication VRI/AV* - Er vanuit gaan dat de verkeersregeling bekend is bij de AV
Expert 6: *Communication VRI/AV* - ervan uitgaande dat er communicatie is tussen VRI en AV
Expert 8: *Communication VRI/AV* - Als AVs praten met verkeerslichten, dan zou dat prima kunnen
Expert 9: *Detection of VRI* - Level 4 zou dat stoplicht goed moeten kunnen zien, dus dat zou niet moeilijk moeten zijn. En dan stopt ie gewoon

C.2 Situation 2 - Signalized intersection (permitted conflict)

Degree of segregation - mentioned by 1 expert
Expert 11: Gescheiden infrastructuur voor fietsers

Vehicle speed - mentioned by 1 expert
Expert 4: Dan kan je AV op een voorzichtigere manier de afslag laten nemen

Cyclist traffic volume - mentioned by 1 expert
Expert 7: In een spitssituatie zou een HDV achter de AV kunnen zien dat er een paar keer een 'gap' zou zijn, waarin een normaal mens misschien wel was afgeslagen

Predictability of behavior - mentioned by 8 experts
Expert 1: Best voorspelbare situatie. Er blijft een factor van onvoorspelbaarheid: bij de fietser, maar ook andere automobilisten
Expert 2: Meer onverwachte gedragingen van fietsers vergeleken met situatie 1: fietser die snel aankomt
Expert 3: Iets ingewikkelder, want er is een mogelijk conflict. Veilig omdat het voor het merendeel geregeld is, een beetje ingewikkeld omdat er tegelijk groen is.
Expert 4: Er vanuit gaande dat er communicatie tussen AV en VRI is dat er bekend is dat het een deelconflict is
Expert 5: Onduidelijker wat er gaat gebeuren. Heeft groen, maar fietsers met hem. Er moet geremd worden voor fietsers, dus fietsers zullen aannemen dat zij door mogen fietsen. Maar ze moeten hier wel op vertrouwen.
Expert 7: AV houdt zich netjes aan de verkeersregels
Expert 9: AV kan nooit volledig op het stoplicht vertrouwen, dat doen wij als menselijke bestuurder ook niet. Je kijkt altijd nog
Expert 10: AV weet de regels om rechts af te kunnen slaan. Dat fietsers voorrang hebben ziet dat voertuig al lang, dat bord is vooral voor mensen gemaakt

Visual communication required - mentioned by 0 experts

Visibility - mentioned by 1 expert
Expert 11: Ik denk dat dit toch nog wel redelijk overzichtelijk is

Infrastructure clarity - mentioned by 3 experts
Expert 6: Naast het conflict is de infra hier veel drukker: veel meer signalen om te lezen die snel moeten worden geïnterpreteerd. Snelle interpretatie is wel iets wat goed gaat zitten
Expert 9: Niet alleen het stoplicht herkennen, maar ook het bord eronder. Goed dat dat bord er staat, staat er volgens mij niet altijd. Fijn voor AV dat dat bord er staat: dan weet ie, ik moet ook op fietsers letten
Expert 11: Typisch onderdeel van Dutch design intersections, dus ik denk cruciaal, deze Nederlandse manier van kruispunten ontwerpen
Expert 11: Overzichtelijke situatie dat je die haaientanden hebt

Cyclist detection accuracy - mentioned by 9 experts
Expert 1: Denk dat AV beter de dode hoek in de gaten kunnen hebben (dan gemiddelde menselijke bestuurder). Zal de fietsers in ieder geval zien, dat verwacht je van een level 4.
Expert 2: Zou veiliger kunnen zijn, mits de technologie goed genoeg is om de fietsers te kunnen detecteren. Maar anders moet je er überhaupt niet aan beginnen.
Expert 3: Afslaand verkeer is altijd lastiger, omdat het (een fietser) niet in de sight-of-view zit. *After asking a question about detection capabilities:* is nu nog niet goed genoeg, maar ik verwacht uiteindelijk van wel. Anders komen ze de weg gewoon niet op.
Expert 6: 2 richting verkeer fietsers, dat maakt het ook complexer.
Expert 7: Level 4 voertuig is hier goed in staat om hier fietsers in beide richtingen te herkennen
Expert 8: Vooral met vrachtwagens, heb je hier nu dodehoekongevallen. De techniek bewijst zich steeds beter dat er minder ongelukken mee zijn. Dat zal met AVs ook zijn, dan voorzie ik hier geen problemen.
Expert 9: Als AV fietsers kan detecteren, dan mag dat binnen het ODD. Op het moment dat AV dat niet kan, urban situation, dan kan die dat nog niet aan. Ik zou het toevoegen als AV in staat is om stoplicht te herkennen, onderbord te lezen en fietsers te detecteren
Expert 10: Wel complex als die fietsers 2-richtingsverkeer hebben, omdat je dan fietsers van de overkant kan krijgen. Tegelijkertijd, door de grote hoeveelheid sensoren zal een AV de fietsers heel snel oppikken. Een mens zal eerder alleen opzij kijken, of achter zich. AV heeft 360 graden feedback.
Expert 11: Misschien dat je in zo'n situatie, dat je het programmeert, dat je er altijd voor zal moeten kiezen dat zo'n auto moet stoppen, en dat je ook zijwaarts met allerlei cameratechnologie wel of niet die andere fietsers moet zien aankomen
Expert 11: *After asking a question about the difference in detection capabilities of AVs and HDVs*: Ik denk dat afhankelijk van die cameratechnologie, dat een AV dat goed zal kunnen inschatten. Ik kan me voorstellen dat dit lijkt op een voetgangersoversteekplaats, waar heel veel andere steden in de wereld van deze voetgangersoversteekplaatsen hebben, is dit een bijna vergelijkbare situatie alleen gaat het om een fietser. Dus ik denk niet dat het te complex zal zijn.

Cyclist traffic violations - mentioned by 2 experts
Expert 2: Meer onverwachte gedragingen van fietsers vergeleken met situatie 1: fietser die snel aankomt, of zoals op het plaatje van de verkeerde kant aankomt
Expert 11: Het ingewikkelde hier is wel, het lijkt alsof die fietser hier tegen de stroom in rijdt. Dat maakt het wel complex. Meestal zou die fietser de andere kant op fietsen en is het eenrichtingsverkeer. Als het dus tweerichtingsverkeer is, dan wordt de taak wel meteen verdubbeld qua complexiteit.

Other - 6 arguments given
Expert 1: *Interaction HDV/AV* - Er blijft een factor van onvoorspelbaarheid: bij de fietser, maar ook andere automobilisten. Die verwachten misschien niet het gedrag van AVs, omdat ze zelf iets niet zien.
Expert 4: *Sensitivity/conservativeness* - De kans is groter dat een AV zich veiliger gedraagt dan een gemiddelde autobestu-

urder, en bijvoorbeeld niet probeert er voorlangs te piepen
Expert 4: *Communication VRI/AV* - Er vanuit gaande dat er communicatie tussen AV en VRI is dat er bekend is dat het een deelconflict is
Expert 7: *Communication VRI/AV* - vaak bij dit soort situaties, waar verkeerslichten in het spel zijn, helpt het als voertuigen connected zijn. Om beter te kunnen anticiperen op de status van de verkeerslichten.
Expert 7: *Sensitivity/conservativeness* - Ik kan me voorstellen dat een AV hier vrij veilig gedrag gaat vertonen, met een ruime marge wacht op fietsers uit beide richtingen. Dat kan op onbegrip van overig verkeer leiden
Expert 8: *Visibility of the AV* - Bij de vorige ziet de fietser de auto ook, en hier komt de auto uit de rug van de fietser en zal de fietser geen direct zicht hebben op de situatie. Daarom iets complexer dan de vorige situatie.

C.3 Situation 3 - Priority intersection (cross traffic)

Degree of segregation - mentioned by 2 experts
Expert 5: Fietser moet stoppen, maar je hebt geen formeel verkeerslicht wat het makkelijker zou maken voor een AV
Expert 9: Nog lastiger, want geen verkeerslicht ofzo.

Vehicle speed - mentioned by 6 experts
Expert 1: er wordt in deze situatie verwacht dat auto's snelheid minderen. Als een AV zich houdt aan de snelheidslimiet, dan is het wel gevaarlijk.
Expert 4: Kans is redelijk dat een fietser denkt over te kunnen steken en het net niet haalt, en dat het voertuig, gegeven zijn snelheid, daarmee een gevaarlijke situatie creëert. Je kan de snelheid laten zakken naar 10/15 km/uur, maar je wilt wel met een redelijke snelheid het kruispunt passeren
Expert 6: Eerder infra aanpassen: maximum snelheid op het kruispunt omlaag brengen.
Expert 6: Als je de maximum snelheid omlaag brengt, zal een AV zich daar eerder aan houden dan een HDV, en kan een AV zelfs veiliger zijn
Expert 8: Met hoge snelheden van de auto, en de AV moet echt tijdig genoeg de fiets moeten herkennen. Op het moment dat de berm te hoog is, en je als fietser niet gezien wordt, dan rij je toch met 60 door
Expert 10: Ik denk ook niet dat een AV hier met 60 aan zal komen
Expert 11: Het is een 60 kilometer per uur weg, en ik kan me voorstellen dat als je het zo programmeert, die auto's hier misschien zelfs wat snelheid terugnemen. Zeker als je zo'n rood vlak ziet, dat de snelheid daar terug gaat. Dat ze daarmee nog voldoende reactietijd hebben als zo'n fietser van rechts komt daar.

Cyclist traffic volume - mentioned by 0 experts

Predictability of behavior - mentioned by 5 experts
Expert 2: Minder geschikt om met AVs af te handelen, omdat er veel signalen zijn dat het de bedoeling is dat de automobilist zijn gedrag aanpast, ondanks de voorrangsregeling. Dat is voor een AV lastig, maar het is wel belangrijk dat dat blijft bestaan, die hybride situaties.
Expert 3: Voorrangsweg, dus het kruisende verkeer moet voorrang geven. Het is niet geregeld met lichten
Expert 5: Fietser moet stoppen, maar je hebt geen formeel verkeerslicht wat het makkelijker zou maken voor een AV
Expert 7: Ongeregelde situaties zijn in het algemeen iets complexer dan geregelde situaties
Expert 10: Als het probleem is dat er een fietser van rechts kan komen, dan is ook de vraag of die ook door rijdt als er een auto aankomt. Dan denk ik dat de AV dit prima aan kan.
Expert 10: Cijfer is een beetje afhankelijk van hoe de fietser zich gedraagt, met hoeveel snelheid die aankomt.

Visual communication required - mentioned by 2 experts
Expert 1: Normaal gesproken is er interactie in deze situatie, om te laten weten dat een auto doorrijdt of dat die rekening houdt met een fietser

Expert 2: Veel conflicten worden hier opgelost door overleg en oogcontact. Er staan wel haaientanden, maar als er een groep fietsers is, zal menig automobilist toch afremmen.
Expert 2: Minder geschikt om met AVs af te handelen, omdat er veel signalen zijn dat het de bedoeling is dat de automobilist zijn gedrag aanpast, ondanks de voorrangsregeling. Dat is voor een AV lastig, maar het is wel belangrijk dat dat blijft bestaan, die hybride situaties.

Visibility - mentioned by 7 experts
Expert 4: Omgevingsfactoren spelen ook een rol: lantaarnpaal, bebossing in de berm (goed bijhouden/snoeien), andere bewegingen die plaats kunnen vinden
Expert 5: Het zicht van AV wordt geblokkeerd door bebossing en is het voornaamste probleem.
Expert 6: Redelijk overzichtelijk ingericht. Je kan de bosjes weghalen voor meer overzicht, maar dat moet je niet te snel willen doen.
Expert 8: De berm die je hier ziet, nu kan je elkaar ook visueel nog zien. Op het moment dat het hoog begroeid is en het zicht verminderd, dan zou ik het gevaarlijk vinden
Expert 8: Met hoge snelheden van de auto, en de AV moet echt tijdig genoeg de fiets moeten herkennen. Op het moment dat de berm te hoog is, en je als fietser niet gezien wordt, dan rij je toch met 60 door. Als de fietser de auto ook niet ziet, is het toch riskant
Expert 9: Onduidelijk dat er een fietser oversteekplaats zit. Zal voor een AV ook lastig zijn om te zien. Dat fietspad ligt ver van de weg af, en die zie je goed doorlopen
Expert 10: Redelijk overzichtelijk. Begroeiing zit denk ik niet zo ver in de weg. De fietser kan niet ineens achter de begroeiing vandaan schieten, het is redelijk laag.
Expert 11: Omdat misschien de zichtbaarheid van die fietsers niet altijd even goed zal zijn, die daar dan van rechts komen. Ik denk dat het nog steeds redelijk overzichtelijk is. Misschien ben ik heel positief of te optimistisch.

Infrastructure clarity - mentioned by 2 experts
Expert 4: Geen belijning meer midden op het vlak
Expert 9: Onduidelijk dat er een fietser oversteekplaats zit. Zal voor een AV ook lastig zijn om te zien. Dat fietspad ligt ver van de weg af, en die zie je goed doorlopen
Expert 9: Er komt ook nog verkeer van links. Ook verwarrend dat het wegvak oranje is, dat suggereert dat fietsers voorrang hebben.

Cyclist detection accuracy - mentioned by 3 experts
Expert 1: Sensoren in de auto zorgen ervoor dat de AV fietsers in de gaten heeft
Expert 7: Wat hier ook lastig kan zijn is de detectie van het verkeer wat loodrecht oversteekt, met name als het van rechts naar links gaat. Maar als het uitgaanspunt is dat een level 4 AV daarmee overweg kan gaan, zou het naar 3 gaan. Ik kan me voorstellen dat er af en toe detectieproblemen zijn
Expert 7: Als een fietser voorrang neemt, vlak voor een AV, zou dat in theorie iets veiliger moeten zijn dan traditionele voertuigen. Omdat je dan niet te maken hebt met de menselijke reactietijd. Dat hangt erg af van de daadwerkelijke capaciteiten van dat voertuig straks. Ik weet dat nu dat voertuigen met ACC juist dat verkeer op korte afstand van rechts komt, pas laat wordt gedetecteerd. Detectie zou in theorie sneller moeten zijn, maar dan heb je nog de verificatiestap nodig, dus de vraag is hoe goed het algoritme is. Dat wordt vaak getuned om veel false positives te vermijden. Dat is denk ik wel lastig in dit soort situaties.
Expert 8: Met hoge snelheden van de auto, en de AV moet echt tijdig genoeg de fiets moeten herkennen. Op het moment dat de berm te hoog is, en je als fietser niet gezien wordt, dan rij je toch met 60 door

Cyclist traffic violations - mentioned by 7 experts
Expert 1: Normaal gesproken is er interactie in deze situatie, om te laten weten dat een auto doorrijdt of dat die rekening houdt met een fietser
Expert 3:*After asking a question about cyclist traffic violations:* Als een fietser toch voorrang neemt, dan zal een AV

onmiddellijk stoppen. Dat zijn klassieke situaties waar alles op gebouwd zal worden. Daar zal een AV veiliger in zijn dan HDV.
Expert 4: Kans is redelijk dat een fietser denkt over te kunnen steken en het net niet haalt, en dat het voertuig, gegeven zijn snelheid, daarmee een gevaarlijke situatie creëert
Expert 6: Fietser die gelijk op fietst met de auto, en ineens oversteekt, dat is waar de risico's zitten. Hoe snel moet daar op gereageerd worden, of niet.
Expert 7: Als een fietser voorrang neemt, vlak voor een AV, zou dat in theorie iets veiliger moeten zijn dan traditionele voertuigen. Omdat je dan niet te maken hebt met de menselijke reactietijd. Dat hangt erg af van de daadwerkelijke capaciteiten van dat voertuig straks. Ik weet dat nu dat voertuigen met ACC juist dat verkeer op korte afstand van rechts komt, pas laat wordt gedetecteerd
Expert 9: Je hebt wel voorrang. Het punt is, voor de veiligheid wil je vergevingsgezindheid: als de ene een fout maakt, dat de ander het kan compenseren. Stel dat een fietser niet die voorrang geeft, als bestuurder stop je dan. Dat moet een AV ook kunnen
Expert 10: Als het probleem is dat er een fietser van rechts kan komen, dan is ook de vraag of die ook door rijdt als er een auto aankomt. Dan denk ik dat de AV dit prima aan kan.
Expert 11: Die fietsers moeten wel stoppen. Maar mocht zo'n fietser door willen rijden, om wat voor reden dan ook, dat snelheidsverschil is dan natuurlijk cruciaal. 60 is dan wel heel hard. Ik denk toch dat dat dan goed zou moeten gaan.
Expert 11: In de meeste gevallen gaat dit natuurlijk altijd goed, omdat de fietsers moeten stoppen. De enige twijfel zit hem dus in het geval dat zo'n fietser de voorrang negeert en wel gewoon oversteekt. Maar dat geldt ook voor de eerste situatie, als een fietser het rode licht negeert. Dan heb je het zelfde probleem als hier eigenlijk. Hier is het misschien nog wat onoverzichtelijker, en dan moet zo'n auto gewoon ingrijpen.

Other - 4 arguments given
Expert 1: *Sensitivity/conservativeness* - Afhankelijk van hoe een AV is ingesteld, bijvoorbeeld snelheid: er wordt in deze situatie verwacht dat auto's snelheid minderen. Als een AV zich houdt aan de snelheidslimiet, dan is het wel gevaarlijk.
Expert 3: *Recognizability of an AV* - De fietser zal een AV herkennen, en zal dan voorzichtiger worden. Onderbuikgevoel: ik hoop maar dat die AV stopt. Ik denk dat een fietser een AV goed zal herkennen, omdat ik denk dat dat een eis zal worden aan AVs.
Expert 4: *HD-map* - Staat wel een voorrangsbord, maar dat kunnen AVs nog niet goed herkennen. Dus dan moet je een digitale kaart toevoegen waaruit duidelijk blijkt dat het een voorrangsweg is
Expert 8: *Distance cycle path to road* - Afstand tussen fietspad en oversteek is goed. Voldoende opstelplek, en genoeg ruimte om de bocht te maken en het verkeer te kunnen zien als fietser. Die afstand is wel heel erg belangrijk. Als die afstand korter wordt, dan durf ik hem niet zo snel toe te voegen aan het ODD ook. Deze afstand zou ongeveer voldoende kunnen zijn.

C.4 Situation 4 - Priority intersection (through traffic)

Degree of segregation - mentioned by 0 experts

Vehicle speed - mentioned by 2 experts
Expert 1: Blijft een conflict waarbij aanpassing van AV snelheid belangrijk is: de snelheid zal laag liggen, omdat de AV een bocht moet maken
Expert 4: Scherpe bocht, dus de snelheid ligt hier sowieso laag en de stopafstand is niet zo groot

Cyclist traffic volume - mentioned by 2 experts
Expert 2: Misschien staat een AV dan wel wat langer te wachten dan een menselijke bestuurder, maar dat kan geen kwaad. Op een gegeven moment beland je misschien wel op de busbaan, als je heel veel fietsers voorrang gaat geven. Leidt misschien tot andere gevaarlijke situaties, maar voor de fietser is het prima
Expert 11: Daar ging het om 1 richtingsverkeer, en hier 2 richtingen, dus dat maakt het wel iets complexer.

Predictability of behavior - mentioned by 6 experts
Expert 2: Zou wel moeten lukken, misschien is de oplossing wel om de fietser overal voorrang te geven met AVs, dan is het in ieder geval duidelijk.
Expert 5: Fietsers hebben wel voorrang, en zullen aannemen dat je als AV stopt
Expert 5: Als AV mag je hier minder fouten maken, want die fout wordt niet opgevangen door fietsers (omdat ze voorrang hebben)
Expert 6: Uitgaande van goed kaartmateriaal in de auto, is de voorrang helder
Expert 9: Is ook ongeregeld
Expert 10: Wat wel complex is dat het tweerichtingsverkeer is van de fietsers. Maar de weg is in kaart gebracht, dus AV weet dat als die afslaat, hij haaientanden tegen komt.
Expert 11: Er zijn ook geen verkeersregelinstallaties, maar toch met afslaand verkeer is dit goed te doen.

Visual communication required - mentioned by 1 expert
Expert 1: Interactie is niet zo van belang: AV moet toch al afremmen om de bocht te maken, en in hetzelfde gemak kan die een fietser voor laten gaan. Fietser ziet de auto ook al afremmen

Visibility - mentioned by 6 experts
Expert 4: Het overzicht is hier beter, moet je wel goed de berm blijven maaien
Expert 5: Veel meer overzicht als AV, geen bladgroei langs de weg. Dus dat is duidelijk
Expert 6: Situatie is erg overzichtelijk, zichtlijnen zijn goed
Expert 8: Met name ook omdat het hier overzichtelijk is
Expert 9: Heel open, goed te zien, dat is een voordeel
Expert 10: Ik denk dat het een overzichtelijke situatie is die door de situatie kan worden opgepikt

Infrastructure clarity - mentioned by 1 expert
Expert 10: Ik vraag me af of de dubbele streep in het midden van de weg bekend is, dat zie je ook niet veel. Dat zijn van die leuke lokale of regionale fratsen. Als het gaat om infra, weet ik niet of hier de CROW richtlijnen zijn gevolgd bij de inrichting van de weg

Cyclist detection accuracy - mentioned by 8 experts
Expert 1: AV zal eerder een fietser opmerken, ook in donkere situaties: dat is hier essentieel
Expert 2: Wel iets complexer dan de eerdere, maar dit is wel een conflict dat af te handelen is, met een goed detectiesysteem.
Expert 3: Met name dat fietsers van 2 kanten kunnen komen. Dat blijft ingewikkeld. Uiteindelijk zal het wel lukken.
Expert 4: Met de sensoriek zou je fietsers van 2 kanten goed moeten kunnen detecteren. Hangt er ook vanaf hoe dat in het voertuig is geregeld. In theorie zou een AV dit beter moeten kunnen dan een HDV.
Expert 7: Ook hier de capaciteit om op korte afstand op een haakse hoek die fietsers te herkennen. Met een goede lidar-set mag dat geen probleem zijn.
Expert 7: *After asking a question about detection performance in adverse weather conditions:* Donker en met zon zou de camera meer moeite hebben, maar ik ga ervan uit dat er sensor fusion gebruikt gaat worden radar, lidar en vision-based. Dit zou voor lidar geen probleem moeten zijn.
Expert 8: Snelheid van de fietser is ook belangrijk. Buiten de bebouwde kom, een speed pedelec is snel, hoe snel reageert een auto op een fietser? Snelheid van gewone fietser (16 km/u) is dan heel anders.
Expert 9: Fietsers is al heel Nederlands, maar dan ook nog van 2 kanten. Dat is voor mensen ook lastig. Dat moet een AV wel geleerd hebben
Expert 9: *After asking a question about learning an AV to detect cyclists from two sides:* fietser van 2 kanten: Wij hebben 2 ogen die dezelfde kant op kijken, zo'n auto kan continu 360 graden kijken. Dat kan die dan uiteindelijk beter.
Expert 11: Daar ging het om 1 richtingsverkeer, en hier 2 richtingen, dus dat maakt het wel iets complexer.

Cyclist traffic violations - mentioned by 0 experts

Other - 6 arguments given
Expert 2: *Sensitivity/conservativeness* - Misschien staat een AV dan wel wat langer te wachten dan een menselijke bestuurder, maar dat kan geen kwaad. Een menselijke bestuurder zal sneller een klein hiaatje accepteren om dat te voorkomen
Expert 4: *HD-map* – Digitale referentie dat je weet dat er een deelconflict zit
Expert 6: *HD-map* - Uitgaande van goed kaartmateriaal in de auto, is de voorrang helder
Expert 7: *Buffer om stil te staan* - Wel een beetje het voordeel dat het afslaande voertuig nog even die buffer heeft waar die kan staan
Expert 8: *Distance cycle path to road* - Net als de vorige situatie, voldoende afstand tussen de weg en het fietspad is belangrijk
Expert 10: *HD-map* - Wat wel complex is dat het tweerichtingsverkeer is van de fietsers. Maar de weg is in kaart gebracht, dus AV weet dat als die afslaat, hij haaientanden tegen komt.

C.5 Situation 5 - Roundabout (cyclists having no priority)

Degree of segregation - mentioned by 0 experts

Vehicle speed - mentioned by 5 experts
Expert 1: Snelheid ligt relatief laag
Expert 2: Minder geschikt, door de lage snelheid is er meer ruimte om te onderhandelen
Expert 4: Snelheid is laag, dus de stopafstand is gering. Dat is het allerbelangrijkste.
Expert 10: AV zal langzaam rijden omdat die naar een rotonde gaat waar die heel duidelijk geen voorrang heeft op auto's. Hij rijdt dus al langzaam, en een aankomende fietser is dan geen probleem.
Expert 11: In dit geval denk ik dat het toch ook goed te doen is, omdat de snelheid er sowieso helemaal uit moet richting zo'n rotonde

Cyclist traffic volume - mentioned by 2 experts
Expert 2: er zijn relatief weinig fietsers. Fietsers die er zijn worden over het hoofd gezien, maar dat doen AVs dan weer niet.
Expert 8: Stel dat het druk is en er staan een aantal auto's. Dan denkt een fietser eerder: ik ga er nog even tussendoor. Hoe goed kan een AV hier op anticiperen, dat weet ik niet. Maakt het toch wel complex.

Predictability of behavior - mentioned by 7 experts
Expert 2: Als je fietsers meer voorrang geeft, wordt het in ieder geval duidelijker.
Expert 5: Het is duidelijk wat er van fietsers wordt verwacht
Expert 6: Dit is een situatie waar echt dingen gaan veranderen hoe mensen zich gaan gedragen. Hoe dan is lastig te voorspellen.
Expert 8: De technologie zal wel de fietser en auto detecteren, en ook wel beter dan de mens die soms iets over het hoofd ziet, maar het gedrag van de fietser kun je niet reguleren.
Expert 9: Over het algemeen is een belangrijk onderscheid: wie heeft er voorrang. Je zou kunnen denken: op het moment dat een AV voorrang heeft, zijn de eisen aan een AV iets lager. Maar we willen ook compenseren voor elkaar. Vanuit veiligheidsoogpunt kun je niet zeggen: AV heeft voorrang, dus hoeft de fietser niet te zien. Wat dat betreft maakt voorrang weer iets minder uit.
Expert 10: Ik moet eerlijk zeggen dat ik rotondes over het algemeen gevaarlijker vind dan gewone kruisingen. Heeft meer te maken met de onduidelijkheid die je kan verwachten, maar dat zeg ik als reguliere bestuurder.
Expert 10: Als AV weet ik dat de fietsers moeten stoppen. Maar afhankelijk van de snelheid waarmee een fietser aan komt

rijden, links of rechts, heeft het systeem al gezien of die intent heeft om door te rijden.
Expert 11: Als ze in de voorrang zitten, dan is het redelijk overzichtelijk
Expert 11: De grotere vraag is, moet je die hele verkeersinfrastructuur niet aanpassen. Moet je dit soort situaties dan niet de fietsers gewoon in de voorrang nemen. In het geval dat er zelfrijdende voertuigen komen. Dat is natuurlijk wel een grotere discussie die je kan voeren.

Visual communication required - mentioned by 4 experts
Expert 1: Hier wel sociale interactie van belang: in de praktijk zie je ook ander gedrag. Alleen als racefietser vertoon je ander gedrag dan als ouder met een kind. Die inschatting kan een AV misschien maken, maar is lastig.
Expert 1: Kracht van de menselijke interactie is er niet, maar dat kun je compenseren met de betere detectie van fietsers
Expert 2: Minder geschikt, door de lage snelheid is er meer ruimte om te onderhandelen
Expert 3: Er zijn veel momenten dat er interactie kan zijn: kruisende fietspad, daarna ook met andere auto's. Van te veel kanten kunnen er dingen gebeuren
Expert 6: Vanuit fietser is een AV nog wel een crime: mensen leer je hier om oogcontact te hebben, maar dat gebeurt niet. Oogcontact met een AV wordt lastig.
Expert 9: AV moet ook aanvoelen of een fietser gaat stoppen, want dan kan een AV doorrijden.
Expert 9: *After asking a question about predicting cyclist intentions:* Ik heb wel het vertrouwen in de technologie dat ze dat uiteindelijk gaan kunnen. Het is toch een kwestie van time-to-collision berekenen en daar een predictie op maken. Daar zijn nu een heleboel studies over gaande. Nu kunnen we het nog niet, maar er wordt hard aan gewerkt om dat te leren.

Visibility - mentioned by 3 experts
Expert 5: Als mens moet je hier op heel veel dingen letten, daar heeft een AV minder last van. Vrij onoverzichtelijke situatie, zo'n rotonde
Expert 6: Qua zicht is dit goed
Expert 11: Als ze in de voorrang zitten, dan is het redelijk overzichtelijk

Infrastructure clarity - mentioned by 1 expert
Expert 6: Niet de gewenste situatie hoe het eruit ziet

Cyclist detection accuracy - mentioned by 5 experts
Expert 1: Detectie van AV zou beter moeten zijn
Expert 1: Kracht van de menselijke interactie is er niet, maar dat kun je compenseren met de betere detectie van fietsers
Expert 2: er zijn relatief weinig fietsers. Fietsers die er zijn worden over het hoofd gezien, maar dat doen AVs dan weer niet.
Expert 4: Het gedrag op de rotonde, het kijkgedrag, op het moment dat zo'n AV dat goed is aangeleerd, zal die minder snel de situatie hebben waar een menselijk bestuurder de fietsers vanuit 2 richtingen niet goed overziet
Expert 4: Hangt ook af van de sensoriek: hoe breed kijkt een AV en hoe goed is die in het onderscheiden van de fietser ten opzichte van de achtergrond. Hier moet je juist breed kijken.
Expert 7: Met een plotselinge oversteker zou die toch op tijd moeten kunnen remmen
Expert 8: Als je met de auto aankomt moet je zowel op de fietser letten als het autoverkeer, daarom gebeuren er ook wel eens ongelukken op rotondes, omdat met op de auto's aan het letten is en niet op de fiets. De technologie zal wel de fietser en auto detecteren, en ook wel beter dan de mens die soms iets over het hoofd ziet, maar het gedrag van de fietser kun je niet reguleren.
Expert 9: Vanuit veiligheidsoogpunt kun je niet zeggen: AV heeft voorrang, dus hoeft de fietser niet te zien. Wat dat betreft maakt voorrang weer iets minder uit.
Expert 10: AV zal langzaam rijden omdat die naar een rotonde gaat waar die heel duidelijk geen voorrang heeft op auto's. Hij rijdt dus al langzaam, en een aankomende fietser is dan geen probleem.

Cyclist traffic violations - mentioned by 8 experts

Expert 4: Een fietser die per ongeluk toch doorfietst, want denkt: dit is een rotonde, of de haaientanden niet snapt. Dat gebeurt.
Expert 5: Ik heb er eerder vertrouwen in dat een AV een fout opvangt, dan dat een fietser een fout opvangt. Dus vandaar dat als een AV voorrang moet verlenen, zie ik meer gevaar dan als een AV geen voorrang moet verlenen. Want ik verwacht dat een AV eerder reageert als er een fout wordt gemaakt door een andere weggebruiker.
Expert 6: Fietsers zullen hier toch regelmatig voorrang nemen, ook al hebben ze dat niet
Expert 8: Ik denk dat ie best wel complex is, omdat je heel erg afhankelijk bent van het gedrag van de fietser. Die zal zich niet altijd eraan houden dat ze hier geen voorrang hebben
Expert 8: Stel dat het druk is en er staan een aantal auto's. Dan denkt een fietser eerder: ik ga er nog even tussendoor. Hoe goed kan een AV hier op anticiperen, dat weet ik niet. Maakt het toch wel complex.
Het kan heel makkelijk gebeuren dat een fietser toch door rijdt, en in of uit de voorrang is altijd verwarrend. Al heeft AV voorrang, wil je toch dat ie stopt als een fietser een fout maakt.
Expert 10: Als AV weet ik dat de fietsers moeten stoppen. Maar afhankelijk van de snelheid waarmee een fietser aan komt rijden, links of rechts, heeft het systeem al gezien of die intent heeft om door te rijden.
Expert 11: En ook hier is er wel weer het risico van fietsers die de voorrang negeren. Maar ik denk dat daar met ingrijpen, omdat de snelheid relatief laag is, dan zou die reactie moeten kunnen worden geprogrammeerd.

Other - 3 arguments given
Expert 1: *Cyclist type* - Hier wel sociale interactie van belang: in de praktijk zie je ook ander gedrag. Alleen als racefietser vertoon je ander gedrag dan als ouder met een kind. Die inschatting kan een AV misschien maken, maar is lastig.
Expert 2: *Informal behavior* - Groepje wielrenners of aantal schoolkinderen of iemand die lang staat te wachten, kun je voorrang geven. Dat heb je met AVs niet meer: het wordt een beetje een autistische bestuurder. Minder veilig, tenzij er dingen worden ingebouwd dat de auto alsnog stopt in dit soort situaties.
Expert 7: *Road width* - Vergeleken met 2 situaties geleden, zou deze iets veiliger zijn, omdat er minder afstand te overbruggen is. Gevoelsmatiger is deze iets veiliger.

C.6 Situation 6 - Roundabout (cyclists having priority)

Degree of segregation - mentioned by 0 experts

Vehicle speed - mentioned by 4 experts
Expert 1: Snelheid ligt een stuk lager
Expert 6: In de basis: binnen de bebouwde kom fietsers in de voorrang, buiten de bebouwde kom fietsers uit de voorrang. Dat is ook qua snelheden die gereden mogen worden logisch.
Expert 8: Deze zal je buiten de kom niet zo vaak tegenkomen. Richtlijn zegt ook, buiten de bebouwde kom fietsers uit de voorrang, heeft ook te maken met de snelheid van de auto's
Expert 10: Het feit dat AV geen voorrang heeft, zal zorgen dat de snelheid waarschijnlijk ook laag is

Cyclist traffic volume - mentioned by 1 expert
Expert 11: De vraag is wat dat dan weer oplevert en hoe die zelfrijdende voertuigen zich in dit soort situaties gedragen, vooral als het een drukke fietsroute is. Ik kan me voorstellen dat bestuurders misschien sneller daar even tussendoor glippen, en dat zelfrijdende voertuigen misschien veel langer zitten te wachten. En dat is natuurlijk wel heel ingewikkeld. Zeker als je buiten de bebouwde kom dit soort situaties hebt, kan dat ook weer misschien tot congestie leiden. Zeker op drukke fietsroutes is dat echt een dilemma. Nederland is zo'n druk fietsland, dan kan je situaties hebben waar je er gewoon nooit tussen komt.

Predictability of behavior - mentioned by 11 experts
Expert 1: AV heeft heldere regel: stoppen voor voetgangers en fietsers

Expert 2: Fietsers hebben voorrang, en een AV weet dat hij voorrang moet geven.
Expert 2: Voor fietsers is deze situatie wel prettig volgens de regels: ze hebben voorrang en dat krijgen ze.
Expert 3: Fietsers denken voorrang te krijgen, maar dat is niet altijd zo
Expert 4: Plek op de weg van fietsers is redelijk voorspelbaar
Expert 5: Fietsers in de voorrang wel net iets gevaarlijker, omdat fietsers geen fouten opvangen van AVs
Expert 6: *After asking a question about comparing the roundabouts:* Basis is voor AV denk ik niet heel relevant, die moet gewoon de regel weten en die hanteren. Voor veiligheid algemeen is uniformiteit het belangrijkst. In de basis: binnen de bebouwde kom fietsers in de voorrang, buiten de bebouwde kom fietsers uit de voorrang. Dat is ook qua snelheden die gereden mogen worden logisch. Ik zou zeggen, laten we dat lekker vasthouden. Logisch en consequent: binnen de bebouwde kom heef doorstroming van fietsers een grotere waarde dan die van een auto, gezien het vervoerssysteem van de toekomst. Richtlijnen die we nu hanteren, moet gewoon hetzelfde blijven voor AVs.
Expert 7: Zou eigenlijk veiliger moeten zijn, ook omdat de AV weet dat de fietsers in de voorrang zitten. Dat zit in de high definition map die ze gebruiken.
Expert 8: Deze juist wel redelijk veilig, omdat het gedrag van een fietser wel voorspelbaar is. Je weet dat een fietser voorrang heeft.
Expert 8: En het gedrag van een fietser is voorspelbaar, dat is mijn belangrijkste reden.
Expert 9: Fietsers in de voorrang is wel overzichtelijker, AV weet dat ie moet stoppen. Dat maakt het iets eenvoudiger, maar voetgangers maakt het weer wat ingewikkelder.
Expert 10: Het feit dat AV geen voorrang heeft, zal zorgen dat de snelheid waarschijnlijk ook laag is
Expert 10: *NAfter asking a question about cyclists with or without priority:* Maakt voor een voertuig niet veel uit, die weet het. Wat het complex maakt, is het gedrag van een fietser. In hoeverre een voertuig in staat is om die intent in te schatten: de snelheid in combinatie met fietser in of uit de voorrang. Dat kan wel verschil uitmaken. Zo lang een fiets voorrang heeft, is dat voor een AV denk ik makkelijker te beoordelen dan een fietser die geen voorrang heeft en het toch neemt.
Expert 11: Misschien moet je toch bepaalde dingen gaan heroverwegen. Ik kan me voorstellen dat dat wel een interessante discussie kan zijn. Dan zou de consequentie zijn dat je alle rotondes buiten de bebouwde kom de fietsers in de voorrang haalt.

Visual communication required - mentioned by 2 experts
Expert 1: Fietsers zullen hier minder snel de interactie zoeken, omdat ze voorrang hebben ze vaker op de automatische piloot rijden.
Expert 2: Het zou jammer zijn als AVs komen er nog meer volgens de regels wordt opgelost, daar wordt het niet altijd per se veiliger van. Juist de situaties waar Nederland relatief goed in is, situaties waar weggebruikers samen zorgen dat het goed komt, die raak je dan kwijt wellicht. Of dan zet je de AV uit. De kans is er dat de regels dan nog strakker worden geïnterpreteerd, en dat is jammer.

Visibility - mentioned by 2 experts
Expert 5: Deze rotonde is wel overzichtelijker
Expert 6: Ziet er even overzichtelijk uit als de vorige

Infrastructure clarity - mentioned by 3 experts
Expert 3: Zo lang er nog verschillende rotondes zijn, zal het nooit veilig worden. Homogeniteit binnen rotondes is belangrijk. Dan maakt het niet uit of het in/uit de voorrang is. Dat is het nu niet, en daarom is het nu levensgevaarlijk.
Expert 9: En herkenbaarheid. Dat het voertuig heel makkelijk kan zien wie er voorrang heeft. Haaientanden lijkt me heel belangrijk, een bord, dat dat er consistent staat. En ook op de goede plekken dat een AV het goed kan zien, niet met een boom ervoor of afgesleten haaientanden. En ook op tijd detecteerbaar, dat een AV afhankelijk van de snelheid voldoende tijd heeft om erop te reageren.
Expert 10: Een haaientand benoemd voor een zebrapad, terwijl het zebrapad is afgesleten. Infrastructuur is overduidelijk afgesleten

Expert 10: Er wordt blokmarkering gebruikt, en dat wordt over het algemeen verkeerd toegepast door wegbeheerders. Blokmarkering, specifiek Nederlands, betekent een scheiding van wegdelen. Blokmarkering zoals hier is geen scheiding van een wegdeel en zou je niet moeten toepassen. Wat hier bedoeld is, is absoluut onduidelijk. Wat de wegbeheerder aan het doen is, ik snap het niet. Als hier langsstrepen hadden gelegen op het fietspad, was het een verplichte plek geweest waar de fietser zijn weg moet vervolgen. Wat overigens voor voetgangers nog wel eens foutief wordt aangezien als: hier heb ik voorrang. Het hele stelsel aan rechten en plichten gebaseerd op infrastructuur zoals die hier ligt, is onoverzichtelijk. Hier zou ik in combinatie met fietsers en AV, zou ik dit niet doen. Als wegbeheerder heb je hier je eigen zaakjes niet op orde, dus hoe kan je van een AV verwachten dat die weet wat er aan de hand is.
Expert 10: Een rood fietspad op de weg is eigenlijk ook een rare situatie. Dit zou betekenen dat er 1 voertuig is wat zich voor de haaientanden mag opstellen, en het 2e voertuig moet voor de haaientanden voor het zebrapad staan.

Cyclist detection accuracy - mentioned by 5 experts
Expert 1: Detectie zal beter zijn, zeker ook omdat de fietspaden meestal mooi in een rondje liggen, en dus binnen de sensoren van AVs vallen.
Expert 4: *After asking a question about comparing roundabouts:* Het is makkelijker voor een AV om fietsers uit de voorrang te hebben, want dan hoef je er minder rekening mee te houden. Maar je moet fietsers in de voorrang ook normaal kunnen hendelen en zien aankomen.
Expert 7: Detectie van de fietser blijft cruciaal in al deze situaties. Komen fietsers van 2 kanten? Zou ook niet uit moeten maken.
Expert 7: Ik weet niet hoe goed de detectiecapaciteit is om onderscheid te maken tussen fietsers en voetgangers. Maar als de AV daar een fout in maakt, bijvoorbeeld fietser als voetganger identificeren, dan zou die nog steeds stoppen. Wellicht iets eerder dan.
Expert 8: Als automobilist moet je op voetganger, fietser en autoverkeer letten: dat is veel om te zien. Een AV kan dit allemaal signaleren en erop anticiperen.
Expert 10: Als er een fietser aan komt zal een AV waarschijnlijk stoppen, omdat de sensoren daar op letten.

Cyclist traffic violations - mentioned by 1 expert
Expert 2: Lijkt me veel veiliger worden, mits de AV ook rekening houdt met fietsers die uit de verkeerde richting komen. Dat is een van de ongevalsfactoren.

Other - 4 arguments given
Expert 5: *AV errors* - Fietsers in de voorrang wel net iets gevaarlijker, omdat fietsers geen fouten opvangen van AVs
Expert 7: *HD-map* - Zou eigenlijk veiliger moeten zijn, ook omdat de AV weet dat de fietsers in de voorrang zitten. Dat zit in de high definition map die ze gebruiken.
Expert 11: *Sensitivity/conservativeness* – De vraag is wat dat dan weer oplevert en hoe die zelfrijdende voertuigen zich in dit soort situaties gedragen, vooral als het een drukke fietsroute is. Ik kan me voorstellen dat bestuurders misschien sneller daar even tussendoor glippen, en dat zelfrijdende voertuigen misschien veel langer zitten te wachten. En dat is natuurlijk wel heel ingewikkeld. Zeker als je buiten de bebouwde kom dit soort situaties hebt, kan dat ook weer misschien tot congestie leiden. Zeker op drukke fietsroutes is dat echt een dilemma. Nederland is zo'n druk fietsland, dan kan je situaties hebben waar je er gewoon nooit tussen komt.
Expert 11: *Sensitivity/conservativeness* – Het enige wat ik hier als ingewikkelde naar voren kan halen is dat zelfrijdende auto's dus eindeloos moeten wachten

C.7 Situation 7 - Access road

Degree of segregation - mentioned by 5 experts
Expert 1: Qua inrichting niet optimaal: je zou bijvoorbeeld fietsstroken verwachten
Expert 5: Fietsstroken vind ik ook veel te klein, zeker gezien deze snelheid
Expert 9: Automobilisten moeten in het midden rijden, tenzij er een tegenligger komt. Dan moeten ze achter de fietser

duiken. Dat is zo Nederlands, dat zal als laatste aan die auto worden aangeleerd.
Expert 9: Je mag in het midden rijden als het kan maar bij een tegemoetkomende auto moet je snappen dat je achter de fietser moet duiken. Echt heel ingewikkeld.
Expert 10: AV moet op het gedeelte dat voor fietsers gereserveerd is uitwijken
Expert 10: Als je twee rode fietspaden hebt en een wegversmalling met 1 rijbaan voor twee richtingen, dan wil ik wel eens zien hoe 2 AVs zich gedragen als ze elkaar tegenkomen. Daar moeten ze echt op getraind zijn.
Expert 11: Dit wordt een lastige, zeker omdat die fietssuggestiestrook hier echt heel smal is
Expert 11: In de meeste gevallen als er fietsers zijn, moet je als auto altijd uitwijken

Vehicle speed - mentioned by 7 experts
Expert 1: Qua inrichting niet optimaal: je zou bijvoorbeeld fietsstroken verwachten, en iets van snelheidsremming
Expert 1: Interactie met HDVs speelt ook: 60km/h, maar buiten de bebouwde kom zal vaak harder gereden worden als er geen fietsers zijn. Als AV 60 km/h rijdt, kan dat irritatie opwekken voor HDVs. Daardoor misschien gevaarlijk gedrag van HDVs, wat weer onveilig kan worden voor fietsers.
Expert 2: AV zal zich beter aan de snelheid houden
Expert 4: Bij lage intensiteiten blijft een AV beter binnen de lijntjes en houdt zicht beter aan de snelheid dan de gemiddelde HDV.
Expert 4: Als AV zacht rijdt, dan kan het, maar dat is niet gewenst. Als die op een normale manier rijdt, dat gaat ie dingen doen die die niet kan.
Expert 5: Vrij hoge snelheid, kan meteen dodelijk zijn bij een ongeval met een fietser
Expert 6: Als je als fietser hier 20 rijdt, en er komt een voertuig met 60km/u voorbij, ook al houdt AV genoeg afstand, het voelt niet fijn. Snelheid en massaverschil is heel groot.
Expert 7: Uitdaging voor automatisch rijden: hoge snelheden en complexe situaties met meerdere verkeersdeelnemers. Dat is hier allebei een beetje. Hoge snelheid en lage complexiteit, of andersom, dat is te doen voor AVs. Dit is een gevaarlijke combinatie, waar de snelheid niet zo hoog is als op snelwegen en de complexiteit niet zo hoog als in de stad, maar de combinatie maakt het gevaarlijk en voor AVs moeilijk te hendelen.
Expert 8: In verband met subjectieve veiligheid, is het wel belangrijk om rekening te houden met de snelheid en afstand waarmee een fietser gepasseerd wordt.

Cyclist traffic volume - mentioned by 6 experts
Expert 4: Als er een beetje verkeer is, dus ochtendspits of schoolspits en dat soort dingen, met groepen fietsers, dan ga je al richting een 4. Als het een weg is waar weinig mensen komen, dan ga je richting een 1 of een 2. Bij lage intensiteiten blijft een AV beter binnen de lijntjes en houdt zicht beter aan de snelheid dan de gemiddelde HDV.
Expert 5: Er moet rekening gehouden worden met te veel andere weggebruikers
Expert 5: Er is weinig ruimte voor foutmarge: stel 2 fietsers en 2 voertuigen, dan kunnen ze allemaal net langs elkaar. Een kleine fout is snel gemaakt, en dan wordt een fietser snel geraakt.
Expert 6: Met name als verkeer uit 2 richtingen komt, of het is druk, dan voelt dat heel naar. Onafhankelijk of het veilig is of niet.
Expert 7: Voor een AV is het lastig om hier de juiste positie op de weg te bepalen. Die is afhankelijk van al dan niet aanwezige fietsers en tegemoetkomend verkeer. Lastig om goed in te schatten.
Expert 8: Heel erg rustig qua fietsers en autoverkeer, zo'n erftoegangsweg
Expert 8: *After asking a question about a situation with larger traffic volumes:* Dan zou ik wel een ander cijfer geven, omdat er dan een hele andere situatie is. Als er veel fietsverkeer is, zou ik überhaupt heel anders naar deze situatie kijken. Moeten de fietsers wel op deze weg, of op een apart fietspad of een fietsstraat.
Expert 11: En dat ze van beide kanten kunnen komen
Expert 11: En met tegemoetkomende fietsers, hoe gaat zo'n AV hierop reageren

Predictability of behavior - mentioned by 3 experts
Expert 2: Kunnen ook wel onverwachte dingen gebeuren, maar die zijn wel beter te detecteren

Expert 4: Plaats op de weg van fietsers is heel onvoorspelbaar
Expert 11: De fietsers slingeren soms wel eens. Hier heb je wel kans op onverwachte situaties

Visual communication required - mentioned by 1 expert
Expert 1: Voor het inhalen van fietsers en tegemoetkomende fietsers, eventueel ook naast elkaar, zal er interactie nodig zijn om veilig te passeren. Dat is ook de essentie van de weg.

Visibility - mentioned by 1 expert
Expert 8: Overzichtelijke situatie, geen zijwegen of wat dan ook

Infrastructure clarity - mentioned by 1 expert
Expert 7: Tegemoetkomend verkeer en AVs hebben niet een duidelijk gemarkeerde strook waar ze in passen om elkaar te passeren, dat is lastig. Ook lastig hier dat het een soort tussenvorm is.

Cyclist detection accuracy - mentioned by 5 experts
Expert 2: AV zal de fietser beter zien
Expert 6: Wat ingewikkeld kan worden, als er een auto tegemoet komt, en de AV moet uitwijken, hoe zit het dan met de detectie van fietsers aan de zijkant. Dat is een technische kwestie, en zal vast opgelost zijn in deze fase.
Expert 8: Ik denk dat een auto in deze situatie al heel snel een fietser kan signaleren en erop kan anticiperen
Expert 9: Voor een mens ook lastig, en lijkt me voor een AV ook heel lastig. Je moet een fietser op de eigen baan detecteren, en ook tegemoetkomende fietser detecteren.
Expert 10: Als er een fietser aankomt zullen ze dat herkennen, dus dat is op zich zelf het probleem niet.

Cyclist traffic violations - mentioned by 0 experts

Other - 7 arguments given
Expert 1: *HDV/AV interaction* - Interactie met HDVs speelt ook: 60km/h, maar buiten de bebouwde kom zal vaak harder gereden worden als er geen fietsers zijn. Als AV 60 km/h rijdt, kan dat irritatie opwekken voor HDVs. Daardoor misschien gevaarlijk gedrag van HDVs, wat weer onveilig kan worden voor fietsers.
Expert 2: *Human error* - AV zal minder snel afgeleid zijn
Expert 2: *Human error* - Bij het inhalen zal een AV een veiligere marge aanhouden
Expert 4: *Sensitivity/conservativeness* - Bij inhalen met tegenliggers, dan zal er door een AV wat meer marge gehouden/ruimte genomen worden.
Expert 6: *Subjective safety* - Onafhankelijk van AVs: compleet onwenselijk. Ik kan me niet voorstellen dat een fietser zich hier prettig voelt. Lastig om deze in te schatten, omdat een algemeen onprettig gevoel overheerst
Expert 6: *Subjective safety* - Voor hoe het voelt voor de fietser, kan het zijn dat die nog liever een automobilist heeft, en dat ie zich meer bedreigd voelt bij een AV. Omdat het voor een fietser minder voorspelbaar voelt, al is het voorspelbaarder.
Expert 6: *Reaction speed* - Qua reactiesnelheid en dergelijke is een AV vrijwel zeker de winnaar en degene die het veiliger gaat maken
Expert 10: *Lack of space* - Hier zie ik wegversmalling en waarschijnlijk niet te gebruiken voor twee richtingen binnen de strepen
Expert 11: *Lack of space* - Dit wordt een lastige, zeker omdat die fietssuggestiestrook hier echt heel smal is. En dat ze van beide kanten kunnen komen

C.8 Situation 8 - Access road (with advisory bicycle lanes)

Degree of segregation - mentioned by 8 experts
Expert 1: Wel wat plek voor de fietser, maar niet veel

Expert 1: Fietssuggestiestroken zijn eigenlijk te smal
Expert 3: Liever met fietssuggestiestrook. Fietssuggestiestrook heeft een andere kleur, dat werkt beter naar de bestuurder toe dan alleen een lijn op de grond: is dat nou de begrenzing van de weg?
Expert 5: *After asking a question about comparing access roads:* Fietssuggestiestrook maakt het veiliger. Bij 1-op-1 interactie zoals in het plaatje, is het duidelijker waar de positie van AV verwacht kan worden. Dat weet de fietser, dat weet de AV.
Expert 7: Gevoelsmatig iets minder complex dan de vorige, omdat je wat meer ruimte hebt
Expert 8: Weinig ruimte voor fietsers om te passeren, die zullen dan daarvoor de rijbaan gebruiken
Expert 9: Vooral het gewenste gedrag van het voertuig, hoe je omgaat met een tegenligger, en combinatie tegenligger en fietser. Als AV lijkt het dat je op het middelste stuk van de weg moet rijden, maar als er een tegenligger komt kan dat niet. Dan moet je op het fietspad. Om dat een AV uit te leggen, is lastig.
Expert 10: Zelfde antwoord als de vorige. En aangezien het rode fietspaden zijn, nog interessanter.
Expert 11: Dit zijn iets bredere en iets duidelijker gekleurde fietssuggestiestroken
Expert 11: Breedte en gekleurde fietssuggestiestroken maken denk ik wel een heel groot verschil voor die herkenbaarheid vanuit zelfrijdende auto's.

Vehicle speed - mentioned by 2 experts
Expert 1: Vergeleken met situatie 7: interactie met HDVs zal beter zijn, omdat de snelheid hier wat lager zal liggen door de aanwezigheid van fietssuggestiestroken.
Expert 1: AV kan denken dat er in het middenstuk 60 gereden mag worden, maar dat is geen veilige passeersituatie
Expert 4: Het is relatief, je vergelijkt het met menselijk gedrag. Op dit type erftoegangsweg vertoont een mens relatief gevaarlijker gedrag dan op de vorige erftoegangsweg. Door de slechter leesbare weg is het lastiger om hard te rijden.

Cyclist traffic volume - mentioned by 5 experts
Expert 5: Er is niet veel ruimte voor 2 voertuigen en 2 fietsers
Expert 5: Fietser inhalen, of tegemoetkomend, zou ik niet zo'n groot probleem vinden, want er is genoeg ruimte. Maar als er een tegemoetkomende auto is, of een stilstaand voertuig, dan wordt het lastiger
Expert 6: Als er 1 moet komen, dan met suggestiestrook. Maar is ook afhankelijk van intensiteit
Expert 8: Fietssuggestiestrook aanwezig zal aangeven dat er meer fietsers zijn dan in de vorige situatie.
Expert 8: Fietser aan beide kanten, en een auto blijft achter de fietser hangen, dan is dat voor de subjectieve veiligheid niet zo fijn
Expert 9: Vooral het gewenste gedrag van het voertuig, hoe je omgaat met een tegenligger, en combinatie tegenligger en fietser. Als AV lijkt het dat je op het middelste stuk van de weg moet rijden, maar als er een tegenligger komt kan dat niet. Dan moet je op het fietspad. Om dat een AV uit te leggen, is lastig.
Expert 11: Maar ook hier kan je de situatie hebben, zeker met beide kanten op met naast elkaar fietsende fietsers
Expert 11: en omdat het twee kanten op gaat. Als er maar aan een kant die fietsers waren, dan is het een ander verhaal. Maar door die tegemoetkomende fietsers, waar er ook situaties kunnen zijn met naast elkaar fietsende fietsers die misschien nog wel slingerend zijn, kan dat denk ik wel heel tricky zijn.

Predictability of behavior - mentioned by 5 experts
Expert 1: bijvoorbeeld als 2 fietsers naast elkaar fietsen buiten de strook, wat mag
Expert 1: Risico is dat de AV zich strak aan de lijntjes houdt: dit is mijn rijbaan en daar verwacht ik geen fietsers
Expert 2: Wellicht lastig om uit te leggen wat de bedoeling is van de middelste strook. Menselijke bestuurders zullen daar rijden, maar dat moet je de AV wel uitleggen. Aan de andere kant gaat er niet veel mis als ze dat niet doen.
Expert 4: Dit geeft iets meer handvatten voor voorspelbaar gedrag van de fietser. Plaats op de weg is helderder
Expert 5: Wel duidelijker wat er van fietsers verwacht kan worden
Expert 5: Bij de vorige kon de positie van het voertuig meer variëren. AV volgt de strepen en maakt er gebruik van om te bepalen waar op de weg hij zich bevindt.
Expert 5: Maar als er een tegemoetkomende auto is, of een stilstaand voertuig, dan wordt het lastiger. Dat zorgt voor

onverwacht gedrag van een fietser, wat lastig is voor een AV.
Expert 11: Maar door die tegemoetkomende fietsers, waar er ook situaties kunnen zijn met naast elkaar fietsende fietsers die misschien nog wel slingerend zijn, kan dat denk ik wel heel tricky zijn.

Visual communication required - mentioned by 1 expert
Expert 1: Ook hier menselijke interactie nodig om veilig elkaar te passeren: bijvoorbeeld als 2 fietsers naast elkaar fietsen buiten de strook, wat mag. Hier wordt echt verkeer gevraagd, en dat is lastig voor een AV.

Visibility - mentioned by 0 experts

Infrastructure clarity - mentioned by 6 experts
Expert 4: Belijning ziet er beter uit, qua leesbaarheid voor AVs
Expert 4: Het is relatief, je vergelijkt het met menselijk gedrag. Op dit type erftoegangsweg vertoont een mens relatief gevaarlijker gedrag dan op de vorige erftoegangsweg. Door de slechter leesbare weg is het lastiger om hard te rijden.
Expert 5: AV volgt de strepen en maakt er gebruik van om te bepalen waar op de weg hij zich bevindt.
Expert 6: Meer een algoritme kwestie: wat doe een AV met een fietssuggestiestrook. Als ze een fietssuggestiestrook gelijk behandelen als normale fietsstrook?
Expert 6: Qua belijning is deze situatie wel herkenbaarder
Expert 7: en het wat duidelijker is om de strook te herkennen
Expert 9: Wel iets makkelijker te herkennen
Expert 9: Ietsje makkelijker dan de vorige: vanwege de kleur van het fietspad. Hiervoor was het ook een fietsstrook, ik interpreteer dat als fietsstrook.
Expert 11: Breedte en gekleurde fietssuggestiestroken maken denk ik wel een heel groot verschil voor die herkenbaarheid vanuit zelfrijdende auto's.
Expert 11: Dit zijn iets bredere en iets duidelijker gekleurde fietssuggestiestroken

Cyclist detection accuracy - mentioned by 2 experts
Expert 7: Detecteren van fietsers en tegenliggers blijft even complex
Expert 10: Als er een fietser aankomt zullen ze dat herkennen, dus dat is op zich zelf het probleem niet.

Cyclist traffic violations - mentioned by 0 experts

Other - 7 arguments given
Expert 1: *Cyclist type* - Wielrenner kan wel meer hebben qua snelheidsverschil, maar voor een moeder met kind of een bakfiets, dan wil je dat de AV gedrag aanpast: snelheid naar beneden, meer uitwijkt, niet strak langs de lijnen.
Expert 3: *Lack of space* - Het is vaak ook heel smal. Ik heb het idee dat een suggestiestrook aan een minimale breedte moet voldoen.
Expert 6: *Subjective safety* - Qua inrichting voelt dit voor een fietser prettiger, qua veiligheid zal het weinig uitmaken
Expert 7: *Environment* - Ik vind hier ook die bomen spannend
Expert 8: *Sensitivity/conservativeness* - Objectieve veiligheid zal omhoog gaan, omdat een auto juist even wacht en niet even snel ertussendoor gaat. Objectief geloof ik wel dat het veiliger wordt, maar subjectief vooralsnog niet
Expert 10: *Lack of space* - Hier zie ik wegversmalling en waarschijnlijk niet te gebruiken voor twee richtingen binnen de strepen
Expert 11: *Lack of space* - Omdat het toch nog redelijk smal is, en omdat het twee kanten op gaat.

C.9 Situation 9 - Bicycle lane

Degree of segregation - mentioned by 8 experts

Expert 3: De wet zegt: je mag er niet overheen. De AV kan dan zeggen: hier ga ik nooit overheen. Dat zou veiliger kunnen zijn. Of dat dan ook gebeurt weet ik niet: in emergency situations moet je misschien wel zeggen: laat maar los. Dat hangt van het algoritme af.
Expert 5: Voor een fietser wel makkelijk om de rijbaan op te komen
Expert 6: Als afslaande fietsers naar links gaan voorsorteren, maakt dat het er niet makkelijker op.
Expert 7: Die AVs kunnen geen kant op, blijven netjes op hun strook rijden
Expert 8: Fietser en AV zitten wel dicht bij elkaar, dus subjectieve onveiligheid is wel een reden
Expert 8: Voldoende breedte ook voor fietsers om elkaar te passeren. Dat is in de vorige situatie niet, daar gebruiken fietsers de rijbaan
Expert 9: AV moet binnen de lijnen blijven, dat moet die wel kunnen
Expert 10: Het wordt interessanter als je de fietser niet vertrouwt en je een fysieke afscheiding gaat doen. Het probleem daarvan is dat dat weer gevaarlijk kan zijn voor de fietser zelf. Verhoogde rijbaanscheiding kan een fietser eroverheen donderen en dan op de weg terecht komen
Expert 10: Het beste is om AVs goed te trainen en tegen fietsers te zeggen: blijf op je strook. Rode fietspaden moeten gewoon in het standaard trainingspakket voor experimentele voertuigen.
Expert 11: Er is natuurlijk een doorgetrokken streep maar dat maakt geen groot verschil.
Expert 11: Dat je hier twee rijstroken hebt, twee richtingen op. Dat is bij die ander niet het geval, waar je moet uitwijken steeds als je tegemoetkomende auto's of tegemoetkomende fietsers hebt.
Expert 11: Als het echt helemaal gescheiden fietsinfrastructuur is, zoals in de eerste of ik geloof tweede situatie, dat is natuurlijk de meest ideale versie. Maar dit komt dan wel in de buurt.
Expert 11: Te doen, omdat het wel echt beter is dan de vorige situatie met gescheiden rijstroken voor auto's, en voor fietsers meer ruimte.

Vehicle speed - mentioned by 2 experts

Expert 4: Als het al gebeurt dat de fietser al dichtbij komt, dan is een AV beter in staat om in te schatten of die er nog veilig en rustig voorbij kan, of omdat ie moet remmen. Meer dan een menselijke automobilist, die misschien eerder met een zijspiegel het stuur aanraakt. Zeker met een snelheid van 50 km/u
Expert 7: AVs zullen wat conservatiever rijden dan HDVs, dus dat is in het voordeel van de fietser
Expert 8: *After asking a question about changing the speed limit from 50 to 30 km/h:* Hoe lager de snelheid, hoe meer speelruimte je hebt om te kunnen anticiperen: zowel AV als fietser. En als er iets gebeurt, is de impact minder heftig. Dit zou wel kunnen met 50, maar 30 is altijd beter.

Cyclist traffic volume - mentioned by 1 expert

Expert 11: Ook hier kan je ook de situatie hebben, zoals je ziet, met twee naast elkaar fietsende fietsers. Maar hier is voldoende ruimte.

Predictability of behavior - mentioned by 6 experts

Expert 1: Wel heel goed kijken hoe het wegvak in elkaar zit, verschilt behoorlijk door heel Nederland. Behoort nog niet tot de standaard Duurzaam Veilig inrichting. Aanwezigheid van een fietsstrook zegt nog weinig over de gevraagde interactie en daarbij complexiteit: er zijn veel andere factoren.
Expert 2: Kan wel eens een lastige zijn, fietsers willen ook wel eens inhalen, en mogen dat ook. De vraag is of een AV daar rekening mee houd
Expert 2: Het lijkt heel vastgelegd met alle doorgetrokken strepen, iedereen in een hokje, maar zo werkt dat niet in de praktijk. De meneer met de tas gaat bijvoorbeeld zo de twee voorgangers inhalen, en dat kan onverwacht zijn
Expert 2: Wel specifiek voorbeeld met doorgetrokken streep. Met een onderbroken streep is het ook ingewikkeld, maar minder onverwacht. Omdat je daar volgens de wet wel de lijn mag overschrijden, wordt het eerder verwacht
Expert 2: Fietsstroken zijn vaak niet eenduidig, er zijn veel uitzonderingen op de basisregels.

Expert 4: De kans dat er iets misgaat met lateraal bewegen is vrij klein
Expert 5: Het is vrij duidelijk waar een voertuig zich mag of moet bevinden
Expert 6: Nog niet eens te maken met de zijweg, maar met name dat de fietsers niet de verplichting hebben om binnen die lijn te blijven. Ze kunnen voor de auto langs zwenken, en dat maakt het complexer
Expert 8: Zullen hier ook geen onverwachte oversteekbewegingen zijn. Fietsers weten als ze willen oversteken dat er veel autoverkeer achter ze zit, dus dan zullen ze stoppen.

Visual communication required - mentioned by 1 expert
Expert 1: Erg afhankelijk hoe een weg is ingedeeld: hier zijn weinig inritten en weinig interactie met zijstraten. Als het puur een gebiedsontsluitingsweg is met interactie op kruispunten, is het een heel ander verhaal dan als er veel langs een weg gebeurt
Expert 1: In principe is deze situatie prima in te schatten voor een AV, zolang de fietser in de langsrichting beweegt, en er alleen een langsconflict is. Als er meer interactie is, dus als fietsers bijvoorbeeld ook de rijbaan oversteken, dan wordt het gevaarlijker.

Visibility - mentioned by 2 experts
Expert 8: Redelijk overzichtelijk
Expert 11: Dit is wel overzichtelijker

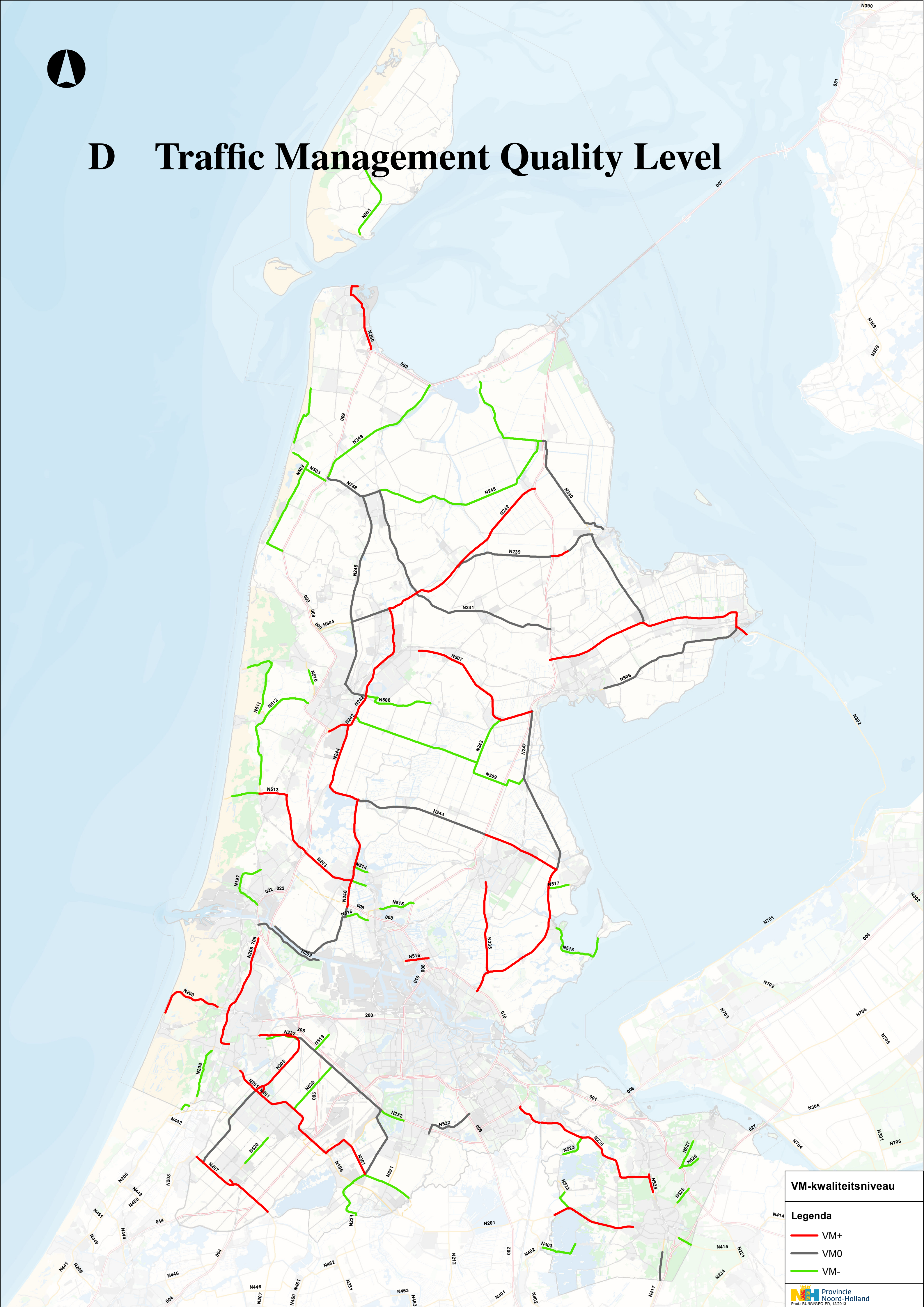
Infrastructure clarity - mentioned by 1 expert
Expert 2: Juridische signaal klopt niet helemaal met het beoogde verkeersgedrag: bijvoorbeeld de doorgetrokken streep die ver doorloopt tot de zijstraat, waardoor de bocht voor een AV dan lastig is. Voor menselijke bestuurders niet zo erg, want die snappen het wel, maar AVs wellicht niet.
Expert 2: Fietsstroken zijn vaak niet eenduidig, er zijn veel uitzonderingen op de basisregels.

Cyclist detection accuracy - mentioned by 2 experts
Expert 4: Als het al gebeurt dat de fietser al dichtbij komt, dan is een AV beter in staat om in te schatten of die er nog veilig en rustig voorbij kan, of omdat ie moet remmen. Meer dan een menselijke automobilist, die misschien eerder met een zijspiegel het stuur aanraakt.
Expert 7: Ik ga er van uit dat level 4 AVs geprogrammeerd worden om een bepaalde afstand tot fietsers te houden. Stel dat dat een meter is, of 60 centimeter. Stel dat er net zoals hier twee fietsers naast elkaar zijn, dan zal een AV mogelijk inschatten dat de afstand te klein is om in te halen, dan zal die erachter blijven. Dat zal wel weer een secundair effect hebben voor het overige verkeer.

Cyclist traffic violations - mentioned by 2 experts
Expert 6: Hoe zit het met training van algoritmes? Nederlandse automobilisten zijn aardig getraind dat fietsers zich niet overal aan houden, maar voordat je algoritmes zo ver hebt dat ze dat herkennen en de intenties van fietsers kunnen lezen.
Expert 9: Vergevingsgezindheid is belangrijk: in de praktijk zie je vaak 3 fietsers naast elkaar, daar moet een AV mee om kunnen gaan. Ook weer typisch Nederlands om naast elkaar te fietsen.

Other - 0 arguments given

D Traffic Management Quality Level



E Infrastructure Readiness Results

This appendix provides the elaborate results of the infrastructure readiness analysis. An overview of the analyzed roads is presented in Table E.1. For all roads, the direction with ascending hectometer posts is analyzed, also known as the right direction. For each road, the corresponding road section is given in hectometers. Some roads are mentioned multiple times, as only road sections are taken into account where the Provincie Noord-Holland is the road authority. Furthermore, each Traffic Management quality level (VM-level) as presented in Appendix D is given. Some roads have different VM-levels on different road sections.

Sections E.1 to E.14 give an overview of the results per road. For each road, the following information is provided:

- An overview of conflict situations between cyclists and Automated Vehicles (AVs), including their locations, conflict type, and a link to the specific conflict situation on Google Street View. The locations refer to the closest hectometer post (HMP). If the Google Street View date was from before 2019, a check for more recent images is done in Cyclomedia Street Smart, to see if there are no infrastructure changes. If the situation has changed, Cyclomedia Street Smart is used to assess the safety of the conflict situation.
- Safety assessment of each conflict situation for all Surrogate Measures of Safety, according to the rubric presented in Section 6.1. Traffic volume is not taken into account, as this data is not available for the majority of conflict situations.
- Additional reasoning if the given score for a Surrogate Measure of Safety is a 'point of attention' (yellow) or 'problem area' (red). This is not done for vehicle speed and predictability of behavior, as no subjective elements are present in the assessment of their safety levels.

Table E.1: Overview of analyzed roads

Road	From (HMP)	To (HMP)	Length (km)	VM-level
N194	0,000	15,944	15,94	VM+
N196	0,000	2,730	2,73	*Not specified*
N197	3,500	8,565	5,07	VM-
N200	19,630	26,083	6,45	VM+
N201	20,709	38,840	18,13	VM+
N201	38,840	43,620	4,78	VM-
N201	69,924	77,476	7,55	VM+
N202	0,438	6,916	6,48	VM0
N203	48,608	60,516	11,91	VM+
N205	10,125	19,900	9,78	VM+
N205	19,900	28,039	8,14	VM0
N206	36,099	37,001	0,90	VM-
N206	38,246	42,662	4,42	VM-
N207	50,741	58,847	8,11	VM+
N208	47,362	57,369	10,01	VM+
N231	16,542	22,050	5,51	VM-
N231	22,050	27,830	5,78	VM0
N232	20,500	23,300	2,80	VM-
N232	23,300	33,100	9,80	VM0
N232	40,000	44,570	4,57	VM0
N243	-0,260	15,880	16,14	VM-

E.1 Results N194

Table E.2: Overview of conflict situations on the N194

Road	ID	VM-level	Location (HMP)	Conflict type	Google Street View link	Street View date	Cyclomedia check
N194	#1	VM+	0,5	Priority intersection (cross traffic)	Link to N194 #1	jun-15	4-4-2020
N194	#2	VM+	0,6	Priority intersection (cross traffic)	Link to N194 #2	aug-18	4-4-2020
N194	#3	VM+	13,1	Signalized intersection	*Not available (outdated)*	-	30-10-2019

Table E.3: Safety scores for all conflict situations on the N194

Road	ID	Vehicle speed	Predictability	Visibility	Infrastructure clarity	Communication required	Cyclist violations
N194	#1	50	Priority (AV)	Clear overview	Good	Sometimes	Sometimes
N194	#2	50	Priority (AV)	Clear overview	Good	Sometimes	Sometimes
N194	#3	80	Signalized	Clear overview	Good	Seldom	Seldom

Reasoning:

- #1 – Visual communication required: cyclists sometimes use visual communication to verify if they have been seen and can safely cross in front of the vehicle
- #1 – Cyclist violations: relatively low vehicle speeds in combination with short crossing distance facilitates occasional violations
- #2 – Visual communication required: cyclists sometimes use visual communication to verify if they have been seen and can safely cross in front of the vehicle
- #2 – Cyclist violations: relatively low vehicle speeds in combination with short crossing distance facilitates occasional violations

E.2 Results N196

Table E.4: Overview of conflict situations on the N196

Road	ID	VM-level	Location (HMP)	Conflict type	Google Street View link	Street View date	Cyclomedia check
N196	#1	*Not specified*	2,7	Signalized intersection	Link to N196 #1	jul-20	

Table E.5: Safety scores for all conflict situations on the N196

Road	ID	Vehicle speed	Predictability	Visibility	Infrastructure clarity	Communication required	Cyclist violations
N196	#1	70	Signalized	Clear overview	Good	Seldom	Seldom

Reasoning:

- *No problem areas or point of attentions that require explanations*

E.3 Results N197

Table E.6: Overview of conflict situations on the N197

Road	ID	VM-level	Location (HMP)	Conflict type	Google Street View link	Street View date	Cyclomedia check
N197	#1	VM-	3,7	Signalized intersection	Link to N197 #1	aug-20	
N197	#2	VM-	4,2	Signalized intersection	Link to N197 #2	aug-20	
N197	#3	VM-	5,7	Roundabout (cyclists having no priority)	Link to N197 #3	aug-20	
N197	#4	VM-	5,8	Roundabout (cyclists having no priority)	Link to N197 #4	aug-20	
N197	#5	VM-	6,8	Roundabout (cyclists having no priority)	Link to N197 #5	aug-20	
N197	#6	VM-	7,7	Roundabout (cyclists having no priority)	Link to N197 #6	aug-20	
N197	#7	VM-	7,8	Roundabout (cyclists having no priority)	Link to N197 #7	aug-20	
N197	#8	VM-	8,5	Roundabout (cyclists having priority)	Link to N197 #8	jun-19	

Table E.7: Safety scores for all conflict situations on the N197

Road	ID	Vehicle speed	Predictability	Visibility	Infrastructure clarity	Communication required	Cyclist violations
N197	#1	50	Signalized	Clear overview	Good	Seldom	Seldom
N197	#2	50	Signalized	Clear overview	Good	Seldom	Sometimes
N197	#3	<50	Priority (AV)	Clear overview	Good	Sometimes	Sometimes
N197	#4	<50	Priority (AV)	Clear overview	Good	Seldom	Sometimes
N197	#5	<50	Priority (AV)	Occluded	Good	Seldom	Sometimes
N197	#6	<50	Priority (AV)	Clear overview	Good	Sometimes	Sometimes
N197	#7	<50	Priority (AV)	Clear overview	Good	Seldom	Sometimes
N197	#8	<50	Priority (cyclist)	Clear overview	Good	Sometimes	Seldom

Reasoning:

- #2 – Cyclist violations: relatively low vehicle speeds in combination with short crossing distance facilitates occasional violations
- #3 – Visual communication required: when entering a roundabout, the relatively low vehicle speeds facilitate visual communication and informal cyclist behavior
- #3 – Cyclist violations: although not having priority, cyclists sometimes take right of way at roundabouts, consciously or unconsciously
- #4 – Cyclist violations: although not having priority, cyclists sometimes take right of way at roundabouts, consciously or unconsciously
- #5 – Visibility: cyclist trajectory path on the right is partly occluded by bushes
- #5 – Cyclist violations: although not having priority, cyclists sometimes take right of way at roundabouts, consciously or unconsciously
- #6 – Visual communication required: when entering a roundabout, the relatively low vehicle speeds facilitate visual communication and informal cyclist behavior
- #6 – Cyclist violations: although not having priority, cyclists sometimes take right of way at roundabouts, consciously or unconsciously
- #7 – Cyclist violations: although not having priority, cyclists sometimes take right of way at roundabouts, consciously or unconsciously
- #8 - Visual communication required: cyclists sometimes use visual communication to verify if they have been seen

E.4 Results N200

Table E.8: Overview of conflict situations on the N200

Road	ID	VM-level	Location (HMP)	Conflict type	Google Street View link	Street View date	Cyclomedia check
N200	#1	VM+	19,6	Priority intersection (cross traffic)	Link to N200 #1	jun-20	
N200	#2	VM+	19,8	Roundabout (cyclists having no priority)	Link to N200 #2	jun-20	
N200	#3	VM+	19,9	Roundabout (cyclists having no priority)	Link to N200 #3	jun-20	
N200	#4	VM+	20,2	Signalized intersection	Link to N200 #4	jun-20	
N200	#5	VM+	21,7	Priority intersection (cross traffic)	Link to N200 #5	jun-20	
N200	#6	VM+	22,9	Priority intersection (cross traffic)	Link to N200 #6	jun-20	
N200	#7	VM+	23,5	No 'official' conflict	Link to N200 #7	jun-20	
N200	#8	VM+	23,7	Priority intersection (cross traffic)	Link to N200 #8	jun-20	
N200	#9	VM+	24,1	Pedestrian crossing	Link to N200 #9	jun-20	
N200	#10	VM+	24,4	No standard situation	Link to N200 #10	jun-20	
N200	#11	VM+	24,7	No standard situation	Link to N200 #11	jun-20	
N200	#12	VM+	25,1	No standard situation	Link to N200 #12	jun-20	
N200	#13	VM+	25,3	No standard situation	Link to N200 #13	jun-20	
N200	#14	VM+	25,5	No standard situation	Link to N200 #14	jun-20	
N200	#15	VM+	25,7	No standard situation	Link to N200 #15	jun-20	
N200	#16	VM+	26,0	No standard situation	Link to N200 #16	jun-20	
N200	#17	VM+	26,1	Roundabout (cyclists having priority)	Link to N200 #17	jun-20	

Table E.9: Safety scores for all conflict situations on the N200

Road	ID	Vehicle speed	Predictability	Visibility	Infrastructure clarity	Communication required	Cyclist violations
N200	#1	<50	Priority (AV)	Occluded	Good	Sometimes	Sometimes
N200	#2	<50	Priority (AV)	Clear overview	Good	Sometimes	Sometimes
N200	#3	<50	Priority (AV)	Clear overview	Good	Seldom	Sometimes
N200	#4	50	Signalized	Clear overview	Good	Seldom	Sometimes
N200	#5	60	Priority (AV)	Clear overview	Unclear	Seldom	Seldom
N200	#6	80	Priority (AV)	Clear overview	Good	Seldom	Seldom
N200	#7	80	Priority (AV)	Clear overview	Unclear	Seldom	Seldom
N200	#8	50	Priority (AV)	Occluded	Good	Seldom	Seldom
N200	#9	50	Shared space	Clear overview	No standard situation	Often	Often
N200	#10	60	Shared space	Clear overview	No standard situation	Often	Often
N200	#11	60	Shared space	Clear overview	No standard situation	Often	Often
N200	#12	60	Shared space	Clear overview	No standard situation	Often	Often
N200	#13	60	Shared space	Clear overview	No standard situation	Often	Often
N200	#14	60	Shared space	Clear overview	No standard situation	Often	Often
N200	#15	60	Shared space	Clear overview	No standard situation	Often	Often
N200	#16	50	Shared space	Clear overview	No standard situation	Often	Often
N200	#17	<50	Priority (cyclist)	Clear overview	Good	Sometimes	Seldom

Reasoning:

- #1 - Visibility: large tree blocks the view
- #1 - Visual communication required: when entering a roundabout, the relatively low vehicle speeds facilitate visual communication and informal cyclist behavior
- #1 - Cyclist violations: relatively low vehicle speeds in combination with short crossing distance facilitates occasional violations
- #2 - Visual communication: when entering a roundabout, the relatively low vehicle speeds facilitate visual communication and informal cyclist behavior
- #2 – Cyclist violations: although not having priority, cyclists sometimes take right of way at roundabouts, consciously or unconsciously
- #3 – Cyclist violations: although not having priority, cyclists sometimes take right of way at roundabouts, consciously or unconsciously
- #4 - Cyclist violations: low vehicle speeds in combination with short crossing distance facilitate violations
- #5 - Infrastructure clarity: no road surface marking present to indicate cyclist crossing
- #7 - Infrastructure clarity: no road surface marking present to indicate cyclist crossing
- #8 – Visibility: trajectory path of cyclists coming from the left is occluded
- #9-16 – Predictability of behavior: color of conflict situation suggests it is a shared space, priority rules are not clear
- #9-16 – Infrastructure clarity: no standard situation according to CROW guidelines and side road surface markings are missing
- #9-16 – Visual communication required: cyclists will use visual communication to see if they can cross
- #9-16 – Cyclist violations: cyclists have no priority, but infrastructure suggests so
- #17 - Visual communication required: cyclists sometimes use visual communication to verify if they have been seen

E.5 Results N201

Table E.10: Overview of conflict situations on the N201

Road	ID	VM-level	Location (HMP)	Conflict type	Google Street View link	Street View date	Cyclomedia check
N201	#1	VM+	20,7	Signalized intersection	Link to N201 #1	jul-20	
N201	#2	VM+	20,7	Signalized intersection	Link to N201 #2	jul-20	
N201	#3	VM+	21,2	Signalized intersection	Link to N201 #3	jul-20	
N201	#4	VM+	21,2	Signalized intersection	Link to N201 #4	jul-20	
N201	#5	VM+	22,4	Signalized intersection	Link to N201 #5	jul-20	
N201	#6	VM+	24,4	Signalized intersection	Link to N201 #6	jul-20	
N201	#7	VM+	24,4	Signalized intersection	Link to N201 #7	jul-20	
N201	#8	VM+	29,7	Signalized intersection	Link to N201 #8	sep-20	
N201	#9	VM-	42,9	Signalized intersection	Link to N201 #9	jul-17	19-10-2020
N201	#10	VM+	71,3	Roundabout (cyclists having no priority)	Link to N201 #10	jun-19	
N201	#11	VM+	73,6	Signalized intersection	Link to N201 #11	jun-19	
N201	#12	VM+	73,7	Signalized intersection	Link to N201 #12	jun-19	
N201	#13	VM+	76,3	Signalized intersection	Link to N201 #13	jun-19	

Table E.11: Safety scores for all conflict situations on the N201

Road	ID	Vehicle speed	Predictability	Visibility	Infrastructure clarity	Communication required	Cyclist violations
N201	#1	80	Signalized	Clear overview	Good	Seldom	Seldom
N201	#2	80	Signalized	Clear overview	Good	Seldom	Seldom
N201	#3	80	Signalized	Clear overview	Good	Seldom	Seldom
N201	#4	80	Signalized	Clear overview	Good	Seldom	Seldom
N201	#5	80	Signalized	Clear overview	Good	Seldom	Seldom
N201	#6	80	Signalized	Clear overview	Good	Seldom	Seldom
N201	#7	80	Signalized	Clear overview	Good	Seldom	Seldom
N201	#8	80	Signalized	Clear overview	Good	Seldom	Seldom
N201	#9	80	Signalized	Clear overview	Good	Seldom	Seldom
N201	#10	<50	Priority (AV)	Clear overview	Good	Seldom	Sometimes
N201	#11	80	Signalized	Clear overview	Good	Seldom	Seldom
N201	#12	80	Signalized	Clear overview	Good	Seldom	Seldom
N201	#13	80	Signalized	Clear overview	Good	Seldom	Seldom

Reasoning:

- #10 – Visual communication required: contrary to other roundabouts, visual communication is seldom facilitated in this situation, because vehicles have a segregated lane to pass the roundabout and thus do not have to wait to enter the roundabout
- #10 – Cyclist violations: although not having priority, cyclists sometimes take right of way at roundabouts, consciously or unconsciously

E.6 Results N202

Table E.12: Overview of conflict situations on the N202

Road	ID	VM-level	Location (HMP)	Conflict type	Google Street View link	Street View date	Cyclomedia check
N202	#1	VM0	0,7	Signalized intersection	Link to N202 #1	jun-19	
N202	#2	VM0	0,8	No 'official' conflict	Link to N202 #2	jun-19	
N202	#3	VM0	1,5	Priority intersection (cross traffic)	Link to N202 #3	jun-19	
N202	#4	VM0	2,4	Priority intersection (cross traffic)	Link to N202 #4	jul-20	
N202	#5	VM0	3,3	Priority intersection (cross traffic)	Link to N202 #5	jul-20	
N202	#6	VM0	4,5	Priority intersection (cross traffic)	Link to N202 #6	jul-20	

Table E.13: Safety scores for all conflict situations on the N202

Road	ID	Vehicle speed	Predictability	Visibility	Infrastructure clarity	Communication required	Cyclist violations
N202	#1	<50	Signalized	Clear overview	Good	Seldom	Seldom
N202	#2	80	Priority (AV)	Clear overview	Unclear	Seldom	Seldom
N202	#3	80	Priority (AV)	Clear overview	Unclear	Seldom	Sometimes
N202	#4	80	Priority (AV)	Clear overview	Good	Seldom	Seldom
N202	#5	80	Priority (AV)	Clear overview	Good	Seldom	Seldom
N202	#6	80	Priority (AV)	Could be occluded	Good	Seldom	Seldom

Reasoning:

- #2 – Infrastructure clarity: no road surface marking present to indicate cyclist crossing
- #3 – Infrastructure clarity: no road surface marking present to indicate cyclist crossing
- #3 – Cyclist violations: short crossing distance facilitates occasional violations, in combination with a road sign indicating presence of cyclists
- #6 – Visibility: cyclists trajectory path on the right could be partly occluded by bushes

E.7 Results N203

Table E.14: Overview of conflict situations on the N203

Road	ID	VM-level	Location (HMP)	Conflict type	Google Street View link	Street View date	Cyclomedia check
N203	#1	VM+	48,6	Signalized intersection	Link to N203 #1	jul-17	12-9-2020
N203	#2	VM+	50,5	Signalized intersection	Link to N203 #2	aug-20	
N203	#3	VM+	50,8	Signalized intersection	Link to N203 #3	aug-20	
N203	#4	VM+	50,9	Signalized intersection	Link to N203 #4	aug-20	
N203	#5	VM+	52,4	Signalized intersection	Link to N203 #5	aug-20	
N203	#6	VM+	52,6	Signalized intersection	Link to N203 #6	aug-20	
N203	#7	VM+	59,6	Priority intersection (cross traffic)	Link to N203 #7	aug-20	
N203	#8	VM+	60,4	Signalized intersection	Link to N203 #8	aug-20	

Table E.15: Safety scores for all conflict situations on the N203

Road	ID	Vehicle speed	Predictability	Visibility	Infrastructure clarity	Communication required	Cyclist violations
N203	#1	50	Signalized	Clear overview	Good	Seldom	Sometimes
N203	#2	50	Signalized	Clear overview	Good	Seldom	Seldom
N203	#3	50	Signalized	Clear overview	Good	Seldom	Seldom
N203	#4	50	Signalized	Clear overview	Good	Seldom	Seldom
N203	#5	80	Signalized	Clear overview	Good	Seldom	Seldom
N203	#6	80	Signalized	Clear overview	Good	Seldom	Seldom
N203	#7	80	Priority (AV)	Clear overview	Good	Seldom	Seldom
N203	#8	80	Signalized	Clear overview	Good	Seldom	Seldom

Reasoning:

- #1 - Cyclist violations: relatively low vehicle speeds in combination with short crossing distance facilitates occasional violations

E.8 Results N205

Table E.16: Overview of conflict situations on the N205

Road	ID	VM-level	Location (HMP)	Conflict type	Google Street View link	Street View date	Cyclomedia check
N205	#1	VM+	16,7	Signalized intersection	Link to N205 #1	jul-20	

Table E.17: Safety scores for all conflict situations on the N205

Road	ID	Vehicle speed	Predictability	Visibility	Infrastructure clarity	Communication required	Cyclist violations
N205	#1	70	Signalized	Occluded	Good	Seldom	Seldom

Reasoning:

- #1 – Visibility: cyclist trajectory path on the right is occluded by a hedge

E.9 Results N206

Many potential dangerous situations are present on the N206. Most importantly, cyclists are not segregated from the carriageway at multiple road sections, leading to continuous conflicts. The number of conflict situations would therefore not be representative for the number of dangerous situations. Therefore, the results of the N206 are not presented in a similar way as all other roads. Some examples of identified conflict situations are as follows:

- Link to Google Street View - N206 example 1
  Multiple driveways are located next to the road, where cyclists could come from. Furthermore, road surface marking to separate lanes is missing.
- Link to Google Street View - N206 example 2
  There is a road sign indicating the presence of cyclists on the carriageway, meaning there are continuous conflicts between AVs and cyclists. In total, this is found for three road sections at the N206.
- Link to Google Street View - N206 example 3
  Just before the second part of the N206 that is managed by the Provincie Noord-Holland (HMP 38.246), there is a yellow road surface marking which is not according to CROW guidelines. Furthermore, cyclists are expected to cross the road, which is also clearly illustrated by the presence of a racing cyclist in the image of Google Street View.

Multiple other conflict situations are identified, but these examples differ from the conflict situations at other provincial roads. Therefore, these are highlighted. Based on the presence of many conflict situations, especially the examples mentioned before, the N206 is not suited for a safe interaction between AVs and cyclists.

E.10 Results N207

No conflict situations with cyclists

E.11 Results N208

Table E.18: Overview of conflict situations on the N208

Road	ID	VM-level	Location (HMP)	Conflict type	Google Street View link	Street View date	Cyclomedia check
N208	#1	VM+	47,8	Signalized intersection	Link to N208 #1	may-19	
N208	#2	VM+	49,0	Signalized intersection	Link to N208 #2	may-19	
N208	#3	VM+	49,1	Signalized intersection	Link to N208 #3	may-19	
N208	#4	VM+	49,9	Signalized intersection	Link to N208 #4	may-19	28-9-2020*
N208	#5	VM+	50,0	Signalized intersection	Link to N208 #5	jun-20	
N208	#6	VM+	50,7	Signalized intersection	Link to N208 #6	jul-17	28-9-2020
N208	#7	VM+	50,7	Signalized intersection	Link to N208 #7	aug-18	28-9-2020
N208	#8	VM+	52,1	Signalized intersection	Link to N208 #8	jun-15	29-9-2020**
N208	#9	VM+	52,2	Signalized intersection	Link to N208 #9	sep-20	
N208	#10	VM+	53,3	Signalized intersection	Link to N208 #10	sep-20	
N208	#11	VM+	53,5	Signalized intersection	Link to N208 #11	sep-20	

**As road works were present in the Google Street View image, the situation was checked for changes in Cyclomedia*
*** Quality of road surface marking has improved*

Table E.19: Safety scores for all conflict situations on the N208

Road	ID	Vehicle speed	Predictability	Visibility	Infrastructure clarity	Communication required	Cyclist violations
N208	#1	70	Signalized	Clear overview	Good	Seldom	Seldom
N208	#2	70	Signalized	Clear overview	Good	Seldom	Seldom
N208	#3	70	Signalized	Clear overview	Good	Seldom	Seldom
N208	#4	70	Signalized	Clear overview	Good	Seldom	Seldom
N208	#5	70	Signalized	Clear overview	Good	Seldom	Seldom
N208	#6	70	Signalized	Clear overview	Good	Seldom	Seldom
N208	#7	70	Signalized	Clear overview	Good	Seldom	Seldom
N208	#8	70	Signalized	Clear overview	Good	Seldom	Seldom
N208	#9	70	Signalized	Clear overview	Good	Seldom	Seldom
N208	#10	70	Signalized	Occluded	Good	Seldom	Seldom
N208	#11	70	Signalized	Clear overview	Good	Seldom	Seldom

Reasoning:

- #10 – Visibility: cyclist trajectory path on the right is occluded by a small hedge

E.12 Results N231

Table E.20: Overview of conflict situations on the N231

Road	ID	VM-level	Location (HMP)	Conflict type	Google Street View link	Street View date	Cyclomedia check
N231	#1	VM-	16,5	Priority intersection (cross traffic)	Link to N231 #1	jun-19	
N231	#2	VM-	16,7	Priority intersection (cross traffic)	Link to N231 #2	jun-19	
N231	#3	VM-	17,8	Priority intersection (cross traffic)	Link to N231 #3	may-19	
N231	#4	VM-	18,7	Signalized intersection	Link to N231 #4	jul-20	
N231	#5	VM-	19,2	Signalized intersection	Link to N231 #5	may-19	
N231	#6	VM-	19,7	Signalized intersection	Link to N231 #6	jul-17	18-11-2020
N231	#7	VM-	20,7	Signalized intersection	Link to N231 #7	jun-20	
N231	#8	VM-	21,3	Signalized intersection	Link to N231 #8	jul-18	18-11-2020
N231	#9	VM0	22,4	Roundabout (cyclists having no priority)	Link to N231 #9	jul-18	19-10-2020
N231	#10	VM0	22,5	Roundabout (cyclists having no priority)	Link to N231 #10	jul-18	19-10-2020
N231	#11	VM0	22,6	Priority intersection (cross traffic)	*Not available (outdated)*		19-10-2020
N231	#12	VM0	22,7	Priority intersection (cross traffic)	*Not available (outdated)*		19-10-2020
N231	#13	VM0	23,9	Priority intersection (cross traffic)	*Not available (outdated)*		19-10-2020
N231	#14	VM0	24,1	Roundabout (cyclists having priority)	*Not available (outdated)*		19-10-2020
N231	#15	VM0	24,2	Roundabout (cyclists having priority)	*Not available (outdated)*		19-10-2020
N231	#16	VM0	24,7	No ‘official’ conflict	Link to N231 #16	jun-20	
N231	#17	VM0	24,9	No ‘official’ conflict	*Not available (outdated)*		19-10-2020
N231	#18	VM0	25,5	Signalized intersection	Link to N231 #18	jul-18	19-10-2020
N231	#19	VM0	26,1	Signalized intersection	Link to N231 #19	jul-18	19-10-2020
N231	#20	VM0	26,7	Signalized intersection	Link to N231 #20	jul-18	19-10-2020
N231	#21	VM0	27,0	Priority intersection (cross traffic)	Link to N231 #21	aug-18	16-11-2020
N231	#22	VM0	27,2	Priority intersection (cross traffic)	Link to N231 #22	aug-18	16-11-2020
N231	#23	VM0	27,6	Roundabout (cyclists having no priority)	Link to N231 #23	jul-18	16-11-2020
N231	#24	VM0	27,8	Signalized / priority intersection	Link to N231 #24	jun-19	
N231/N232	#25	VM0	27,8	Signalized intersection	Link to N231 #25	jun-20	

Table E.21: Safety scores for all conflict situations on the N231

Road	ID	Vehicle speed	Predictability	Visibility	Infrastructure clarity	Communication required	Cyclist violations
N231	#1	50	Priority (AV)	Clear overview	Good	Sometimes	Sometimes
N231	#2	50	Priority (AV)	Clear overview	Good	Sometimes	Sometimes
N231	#3	80	Priority (AV)	Clear overview	Good	Seldom	Sometimes
N231	#4	80	Signalized	Clear overview	Good	Seldom	Seldom
N231	#5	80	Signalized	Clear overview	Deteriorated	Seldom	Seldom
N231	#6	80	Signalized	Clear overview	Good	Seldom	Seldom
N231	#7	80	Signalized	Clear overview	Good	Seldom	Seldom
N231	#8	80	Signalized	Clear overview	Good	Seldom	Seldom
N231	#9	<50	Priority (AV)	Clear overview	Good	Seldom	Seldom
N231	#10	<50	Priority (AV)	Clear overview	Good	Seldom	Sometimes
N231	#11	60	Priority (AV)	Clear overview	Good	Seldom	Sometimes
N231	#12	60	Priority (AV)	Clear overview	Good	Seldom	Sometimes
N231	#13	60	Priority (AV)	Clear overview	Good	Seldom	Sometimes
N231	#14	<50	Priority (cyclist)	Clear overview	Good	Sometimes	Seldom
N231	#15	<50	Priority (cyclist)	Clear overview	Good	Sometimes	Seldom
N231	#16	50	Priority (AV)	Clear overview	Unclear	Seldom	Seldom
N231	#17	50	Priority (AV)	Clear overview	Unclear	Seldom	Seldom
N231	#18	50	Signalized	Clear overview	Good	Seldom	Seldom
N231	#19	50	SIgnalized	Clear overview	Good	Seldom	Seldom
N231	#20	80	Signalized	Clear overview	Good	Seldom	Seldom
N231	#21	80	Priority (AV)	Clear overview	Good	Seldom	Sometimes
N231	#22	80	Priority (AV)	Clear overview	Good	Seldom	Sometimes
N231	#23	<50	Priority (AV)	Occluded	Good	Sometimes	Sometimes
N231	#24	80	Signalized	Clear overview	Conflicting priority rules	Seldom	Seldom
N231/N232	#25	<50	Signalized	Clear overview	Good	Seldom	Sometimes

Reasoning:

- #1 – Visual communication required: cyclists sometimes use visual communication to verify if they have been seen and can safely cross in front of the vehicle
- #1 – Cyclist violations: relatively low vehicle speed in combination with short crossing distance facilitates occasional violations
- #2 – Visual communication required: cyclists sometimes use visual communication to verify if they have been seen and can safely cross in front of the vehicle
- #2 – Cyclist violations: relatively low vehicle speed in combination with short crossing distance facilitates occasional violations
- #3 – Cyclist violations: short crossing distance facilitates occasional violations, in combination with road sign indicating presence of cyclists
- #5 – Infrastructure clarity: deteriorated road surface marking indicating cyclist crossing
- #9 – Contrary to other roundabouts, visual communication and cyclist violations is not facilitated due to the double lane
- #10 – Cyclist violations: relatively low vehicle speed in combination with short crossing distance facilitates occasional violations
- #11 - Cyclist violations: short crossing distance facilitates occasional violations
- #12 - Cyclist violations: short crossing distance facilitates occasional violations
- #14 - Visual communication required: cyclists sometimes use visual communication to verify if they have been seen
- #15 - Visual communication required: cyclists sometimes use visual communication to verify if they have been seen
- #16 – Infrastructure clarity: no road surface marking present to indicate cyclist crossing
- #17 – Infrastructure clarity: no road surface marking present to indicate cyclist crossing
- #21 – Cyclist violations: road sign indicating presence of cyclists (and horses)
- #22 – Cyclist violations: road sign indicating presence of cyclists (and horses)
- #23 – Visibility: cyclist trajectory path is partly occluded due to the fences
- #23 – Visual communication required: when entering a roundabout, the relatively low vehicle speeds facilitate visual communication and informal cyclist behavior
- #23 – Cyclist violations: although not having priority, cyclists sometimes take right of way at roundabouts, consciously or unconsciously

- #23 – Other: multiple BMV accidents happened in the past at this conflict situation
- #24 – Infrastructure clarity: conflicting road infrastructure (give-way) with priority regulated by traffic lights
- #25 – Cyclist violations: short crossing distance facilitates occasional violations

E.13 Results N232

Table E.22: Overview of conflict situations on the N232

Road	ID	VM-level	Location (HMP)	Conflict type	Google Street View link	Street View date	Cyclomedia check
N232	#1	VM-	23,1	Roundabout (cyclists having no priority)	Link to N232 #1	jul-20	
N232	#2	VM-	23,1	Roundabout (cyclists having no priority)	Link to N232 #2	jul-20	
N232	#3	VM0	23,5	Roundabout (cyclists having no priority)	Link to N232 #3	sep-20	
N232	#4	VM0	25,3	Signalized intersection	Link to N232 #4	sep-20	
N232	#5	VM0	27,3	Signalized intersection	Link to N232 #5	jul-20	
N232	#6	VM0	27,4	Signalized intersection	Link to N232 #6	jul-20	
N232	#7	VM0	29,4	Signalized intersection	Link to N232 #7	jun-19	
N232	#8	VM0	29,8	Signalized intersection	Link to N232 #8	sep-20	
N232	#9	VM0	30,3	Priority intersection (cross traffic)	Link to N232 #9	sep-20	
N232	#10	VM0	31,3	Signalized intersection	Link to N232 #10	sep-20	
N232	#11	VM0	40,7	Signalized intersection	Link to N232 #11	oct-20	
N232/N231	#12	VM0	40,7	Signalized / priority intersection	Link to N232 #12	jun-19	
N232	#13	VM0	42,8	Signalized intersection	Link to N232 #13	oct-20	
N232	#14	VM0	43,4	Signalized intersection	Link to N232 #14	sep-20	

Table E.23: Safety scores for all conflict situations on the N232

Road	ID	Vehicle speed	Predictability	Visibility	Infrastructure clarity	Communication required	Cyclist violations
N232	#1	<50	Priority (AV)	Clear overview	Good	Sometimes	Sometimes
N232	#2	<50	Priority (AV)	Clear overview	Good	Seldom	Sometimes
N232	#3	<50	Priority (AV)	Clear overview	Good	Seldom	Sometimes
N232	#4	80	Signalized	Occluded	Good	Seldom	Seldom
N232	#5	80	Signalized	Occluded	Good	Seldom	Seldom
N232	#6	80	Signalized	Occluded	Good	Seldom	Seldom
N232	#7	80	Signalized	Clear overview	Good	Seldom	Seldom
N232	#8	80	Signalized	Clear overview	Good	Seldom	Sometimes
N232	#9	80	Priority (AV)	Clear overview	Good	Seldom	Sometimes
N232	#10	80	Signalized	Clear overview	Good	Seldom	Seldom
N232	#11	70	Signalized	Occluded	Good	Seldom	Seldom
N232/N231	#12	<50	Signalized	Clear overview	Conflicting priority rules	Seldom	Seldom
N232	#13	70	Signalized	Clear overview	Good	Seldom	Seldom
N232	#14	70	Signalized	Clear overview	Good	Seldom	Seldom

Reasoning:

- #1 – Visual communication required: when entering a roundabout, the relatively low vehicle speeds facilitate visual communication and informal cyclist behavior
- #1 – Cyclist violations: although not having priority, cyclists sometimes take right of way at roundabouts, consciously or unconsciously
- #2 – Cyclist violations: although not having priority, cyclists sometimes take right of way at roundabouts, consciously or unconsciously
- #3 – Cyclist violations: although not having priority, cyclists sometimes take right of way at roundabouts, consciously or unconsciously
- #4 – Visibility: cyclists trajectory path on the right is occluded by bushes and a fence
- #5 – Visibility: cyclists trajectory path on the right is occluded by a fence
- #6 – Visibility: cyclists trajectory path on the right is occluded by a fence
- #8 – Cyclist violations: Although officially a pedestrian crossing, cyclists (and pedestrians) might cross. Short crossing distance and proximity to bus stop facilitates occasional violations
- #9 – Cyclist violations: short crossing distance and proximity to a bus stop facilitates occasional violations
- #11 – Visibility: cyclists trajectory path on the right is occluded by a fence
- #12 – Infrastructure clarity: conflicting road infrastructure (give-way) with priority regulated by traffic lights
- #13 – Other: actually a pedestrian crossing, but cyclists can be expected

E.14 Results N243

Table E.24: Overview of conflict situations on the N243

Road	ID	VM-level	Location (HMP)	Conflict type	Google Street View link	Street View date	Cyclomedia check
N243	#1	VM-	1,5	Priority intersection (cross traffic)	Link to N243 #1	jun-19	
N243	#2	VM-	3,1	Priority intersection (cross traffic)	Link to N243 #2	aug-17	18-2-2020
N243	#3	VM-	5,8	Priority intersection (cross traffic)	Link to N243 #3	jun-15	29-6-2019
N243	#4	VM-	5,9	Priority intersection (cross traffic)	Link to N243 #4	jun-15	29-6-2019
N243	#5	VM-	7,1	Signalized intersection	Link to N243 #5	jun-15	18-2-2020
N243	#6	VM-	7,2	Signalized intersection	Link to N243 #6	jun-15	18-2-2020
N243	#7	VM-	8,0	Priority intersection (cross traffic)	Link to N243 #7	aug-17	18-2-2020
N243	#8	VM-	8,4	Priority intersection (cross traffic)	Link to N243 #8	jun-15	5-1-2020
N243	#9	VM-	9,6	Signalized intersection	Link to N243 #9	jun-15	5-1-2020
N243	#10	VM-	9,7	Signalized intersection	Link to N243 #10	jun-15	5-1-2020
N243	#11	VM-	11,5	Roundabout (cyclists having no priority)	Link to N243 #11	jun-15	5-1-2020
N243	#12	VM-	12,4	Priority intersection (cross traffic)	Link to N243 #12	jul-19	
N243	#13	VM-	13,0	Priority intersection (cross traffic)	Link to N243 #13	jul-19	
N243	#14	VM-	14,8	Signalized intersection	Link to N243 #14	jul-19	

Table E.25: Safety scores for all conflict situations on the N243

Road	ID	Vehicle speed	Predictability	Visibility	Infrastructure clarity	Communication required	Cyclist violations
N243	#1	80	Priority (AV)	Clear overview	Good	Seldom	Seldom
N243	#2	50	Priority (AV)	Clear overview	Good	Seldom	Seldom
N243	#3	80	Priority (AV)	Clear overview	Good	Seldom	Seldom
N243	#4	80	Priority (AV)	Clear overview	Good	Seldom	Seldom
N243	#5	80	Signalized	Clear overview	Good	Seldom	Seldom
N243	#6	80	Signalized	Clear overview	Good	Seldom	Seldom
N243	#7	80	Priority (AV)	Clear overview	Unclear	Seldom	Seldom
N243	#8	80	Priority (AV)	Clear overview	Good	Seldom	Seldom
N243	#9	80	Signalized	Clear overview	Good	Seldom	Seldom
N243	#10	80	Signalized	Could be occluded	Good	Seldom	Seldom
N243	#11	<50	Priority (AV)	Clear overview	Deteriorated	Sometimes	Sometimes
N243	#12	80	Priority (AV)	Clear overview	Unclear	Seldom	Seldom
N243	#13	80	Priority (AV)	Clear overview	Unclear	Seldom	Seldom
N243	#14	80	Signalized	Clear overview	Good	Seldom	Sometimes

Reasoning:

- #8 – Infrastructure clarity: no road surface marking present to indicate cyclist crossing
- #10 – Visibility: cyclist trajectory path could be partly occluded due to a bicycle parking next to the road
- #11 – Infrastructure clarity: quality of road surface marking is deteriorated
- #11 – Visual communication required: when entering a roundabout, the relatively low vehicle speeds facilitate visual communication and informal cyclist behavior
- #11 – Cyclist violations: although not having priority, cyclists sometimes take right of way at roundabouts, consciously or unconsciously
- #12 - Infrastructure clarity: no road surface marking present to indicate cyclist crossing
- #13 - Infrastructure clarity: no road surface marking present to indicate cyclist crossing
- #14 – Cyclist violations: although this intersection is prohibited for cyclists, it is the shortest way to cross the N243, expectedly leading to some cyclists crossing