Perception of traffic safety for cyclists at unsignalized intersections in the Netherlands. A case study in the city of Groningen.

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Abstract

Perceptions of cycling safety have widely been studied across North America over recent years in attempts to stimulate cycling as a mode of transportation. This is the result of the fact that low perceptions of safety are the largest barrier to cycling. Especially among vulnerable groups of cyclists, an improvement in the perceptions of safety could improve cycling rates. This subject has not been explored as widely in the Dutch context, as a result of the pre-existing strong cycling culture. This thesis attempts to fill this gap in the literature by exploring what factors influence perceptions of cycling safety, at unsignalized intersections in particular. It does so by investigating factors that have been identified in the international literature, for their effects on perception of cycling safety in the municipality of Groningen. To this end, a sample of 100 intersections is selected and evaluated on these characteristics. Furthermore, an online survey is carried out to gather data on the perceptions of safety for cyclists at these intersections. This online survey represents intersections by an image and top-down illustration. Respondents rate their perceptions of safety on a 5-point Likert scale. Finally, a combination of t-tests, ANOVA and linear regression is applied in order to identify both physical intersection characteristics and individual demographic characteristics that influence cyclists' perceptions of safety. The results of these statistical analyses indicate an important role for the presence of cycling infrastructure continued across the intersection, in determining the perception of safety. Furthermore, age is found to be the most important individual characteristic which affects perceptions of cycling safety. Elderly cyclists are found to be the most vulnerable cyclists, therefore their perceptions of safety should be given particular attention in cycling path and street design considerations in the Netherlands.

Keywords: cyclist traffic safety, perceived safety, traffic risk, unsignalized intersections, intersection treatments, vulnerable cyclists, linear regression

Contents

List of Figures

Figure 5.1: left: type 2a intersection, right: type 2b intersection

Figure 5.2: left: type 3a intersection, middle: type 3a intersection, right: type 3c intersection

List of Tables

List of abbreviations

ANOVA analysis of variance

BCI bicycle compatibility index

BLOS bicycle level of service

BRON Bestand geregistreerde ongevallen Nederland

DOT department of transportation

GIS geographical information systems

ISI intersection safety index

LOS level of service

LTS level of traffic stress

M mean

NWB Nederlands wegenbestand

QR quick response

SD standard deviation

SPSS statistical package for the social sciences

URL uniform resource locator

1 Introduction

1.1 Cycling safety

The Netherlands experience relatively low numbers of cycling fatalities at 1.1 per 100 million km cycled, in comparison to 3.0 for the United Kingdom and 5.8 for the United States (Pucher & Buehler, 2008). Yet in the Netherlands, cyclists still make up 25% of the total number of fatal road accident victims. For serious road injuries this number is even 60% (Shepers et al., 2017). Therefore cyclists remain among the most vulnerable road users. Most of these traffic accidents occur at intersections, especially in cities, where activity is concentrated and cycling rates are the highest (Reurings et al., 2012; Hu et al., 2018). This traffic safety risk associated with cycling forms an important deterrent from cycling (Ng et a., 2017). There is however a difference between perceived cycling safety and actual cycling safety. Perceived safety relates to how traffic is experienced by cyclists, whereas actual safety is the actual likelihood of crashes. For behavioral response, it is the former that plays the most important role (Manton et al., 2016). Perceived safety and risk are identified by the international literature as the primary barriers to cycling for both leisure and commuting trips (Lawson et al., 2013; Manton et al., 2016). Furthermore, perceived safety is the most important determinant in route choice for cyclists (Manton et al., 2016). Therefore, perceptions of safety play a central role in how cycling is viewed as a mode of transport. By improving perceptions of cycling safety, it will become a more attractive alternative to motorized modes of transport. Therefore, this MSc thesis project seeks to explore what factors determine perceptions of cycling safety.

1.2 Benefits to cycling

Promoting cycling is a widely pursued policy goal. Policymakers prefer cycling as a mode of transport, over the car, because cycling offers a multitude of benefits. These benefits of cycling are well explored in the scientific literature. They include benefits to personal health and wellbeing for the cyclist themselves, by preventing obesity and cardiovascular diseases and reducing cancer risks (Oja et al., 2011; Hu et al., 2018). Cycling trips that replace motorized vehicle trips have additional benefits for the environment and the health of the wider population by reducing air pollution (Lindsey et al., 2011). Increasing the modal share of cycling has also been found to offer economic benefits including reduced congestion, less need for parking space and reduced energy consumption (Hu et al., 2018). These combined benefits are the reason cycling is being promoted as an alternative mode of transport around the world. In order to achieve a greater modal share for cycling, researchers in North-America and Australia have focused on improving perceptions of cycling safety for roadway segments and for intersections (Akar & Clifton, 2009; Ng et al., 2017).

1.3 Cycling safety in the Netherlands

In the Netherlands, the subject of perceived traffic safety for cyclists remains largely unexplored (Ton et al., 2020). Firstly, this is the result of the strong ‘cycling culture’ in the Netherlands (Ton et al., 2020). Residents in the Netherlands learn to ride a bicycle at a young age and it is one of the main modes of transport, as 27% of trips are made by bicycle (CBS, 2018). This strong cycling culture means that cycling skill is generally high and cycling is mostly not perceived as very dangerous (Pucher & Buehler, 2008). Another reason why perceived safety for cyclists is not investigated more in the Netherlands is the high level of actual traffic safety for cyclists. Since the 1970s policy has been focused on improving traffic safety for cyclists in order to stimulate cycling (Pucher & Buehler, 2008). Such policies have been very effective, making the Netherlands one of the most bicycle-friendly countries in the world (Ton et al., 2020). However, much of this bicycle-friendly infrastructure is adapted to the average Dutch cyclist. More vulnerable, less-skilled, cyclists are at risk of being overlooked. Most cyclists in the Netherlands can be grouped in the 'strong and fearless' category, in the typology of cyclists by Geller (2007). This classification sorts cyclists into four types, based on their level of cycling skill and their attitudes towards cycling. This classification of cyclists forms a basis for assessing the suitability of different types of infrastructure to different types of cyclists and will be discussed in more detail in section 2.1. For now it is important to note that the classification of strong & fearless does not apply to all Dutch cyclists. As pointed out by Ferenchak and Marshall (2020), children and elderly cyclists tend to be less confident in their ability, leading to lower perceptions of safety. Therefore, these groups often belong to a more vulnerable group of cyclists. In the city of Groningen the same is potentially true for a great deal of international students, who tend to be less skilled at cycling than the average of the Dutch population. In the municipality of Groningen the elderly make up 15% of the population, children (4-12 years) make up 6.5% and international students make up 5.2% (CBS, 2021; Groningen City Monitor, 2020). These groups account for a significant part (total 26.7%) of the population that is likely to be somewhat vulnerable. Age and cultural background are not the only determinants for cycling skill and vulnerability while cycling. The roles of gender and regularity of cycling are also often cited in the literature (Dejoy, 1992; Rundmo & Iversen, 2004). In the Dutch context however, the relation between age, gender and cultural background and perceptions of cycling safety are yet to be explored.

1.4 Aim

The aim of this MSc thesis project is to identify intersection characteristics that affect perceived traffic safety for cyclists, as a means to formulate a set of guiding principles for the design of intersections in the built-up environment. Furthermore, the project will investigate the role of individual characteristics on general perceptions of cycling safety. These insights will allow practitioners to improve perceived traffic safety for cyclists, as a means of lowering the barrier for deciding on cycling trips. The importance in increasing perceived traffic safety, is therefore the positive effect that it will have on traffic mode choice and mobility for vulnerable cyclists. Recent studies, like one by Manaugh, Boisjoly and El-Geneidy (2016) suggest that perceived safety plays an influential role in modal choice. Dill & Carr (2003) found that cities with more bicycle-specific infrastructure show higher levels of bicycle commuting. The current research project builds on such findings by exploring what aspects of infrastructure design play a role in safety perceptions. In general, improving perceived safety will help to increase the attractiveness of cycling as a mode of transport. Ideally cycling would replace some of the trips taken by cars and take up a larger part of the modal split. For much of the Dutch, non-vulnerable, population this may not be realistic, as most shorter-distance trips are already taken by bicycle (CBS, 2018). This is why additional attention is being paid to vulnerable groups of cyclists, who make up a significant part of the population and are more affected by perceptions of safety.

1.5 Research questions

This MSc thesis project will expand on existing literature by investigating the perceptions of safety for cyclists in the Dutch context. This subject has received continuously increasing attention in North-America and other parts of the western world, in an attempt to improve the attractiveness of the bicycle in modal choice (Ferenchak & Marshall, 2020; Lawson et al., 2013; Lindsey et al., 2011; Manaugh et al., 2016). As touched upon earlier, this is not as much the case in the Netherlands. The reason is that both infrastructure and its users in the Netherlands are well adapted to cycling being one of the main modes of transport. Therefore, this MSc thesis project will try to identify a set of factors that influence perceived safety for cyclists on intersections. Therefore, this MSc thesis project will try to answer the question:

What factors determine the perceptions of traffic safety for cyclists at unsignalized intersections in the municipality of Groningen?

First, the selected sample of intersections under study is divided into a typology of intersections. The reason is that not all intersections are similar enough to justify a direct comparison. Comparing between the types of intersections will answer the first sub question:

RQ*1: What types of intersections are perceived as safe and unsafe by cyclists?*

Answering this first sub question will give insight into what types of intersections are generally perceived as unsafe. This insight will help planning practitioners identify those intersections where changes or additional safety measures might be needed.

Second, a more in-depth analysis will identify those individual characteristics of the intersections that play a significant role in determining safety perceptions. This analysis will help answer the second sub question:

RQ2: What characteristics in the intersections correspond with higher or lower levels of perceived safety for cyclists?

Identifying factors that correspond to higher or lower levels of perceived safety will be valuable in the future design of intersections. Factors that relate to higher levels of safety perceptions could be implemented in more intersections in order to improve their perceived safety.

Third, the international literature suggests that safety perceptions differ significantly between groups based on demographic characteristics. The accuracy of this statement for the Dutch population will be tested in answering the third sub question:

RQ3: Which groups of cyclists are the most vulnerable and how do their perceptions of cycling safety compare to those of skilled cyclists? Answering this sub question will provide insight into what groups of cyclists are vulnerable in the Netherlands. This insight may provide a starting point for future research. Cycling as a means of transport should be comfortably accessible to all, so the infrastructure should be designed to accommodate the most vulnerable users. Focusing on the safety perceptions of those most vulnerable users will therefore offer the most inclusive insights.

1.6 Thesis outline

The present report is structured as follows: the report starts by introducing the reader to the background of traffic safety research through a literature review (Ch.2). The aim of this literature review is to identify factors that have previously been found to influence perceptions of traffic safety. Most importantly, a variety of models predicting perceptions of traffic safety will be discussed in depth. The report continues by proposing a typology of unsignalized intersections. In Chapter 3, the methodology deals with the selection of intersections to be investigated, the operationalization of variables and the creation and distribution of the survey. Next, in Chapter 4, the data section discusses the outcomes of statistical testing. In the discussion section (Ch.5), these outcomes are discussed in relation to the existing literature. Finally, the conclusion section (Ch.6) includes a summary of the conclusions in answering the research questions. The report finishes with a reflection on the research process in Chapter 7.

2 Literature Review

This chapter aims to provide the reader with context on cycling safety research. In doing so, it will investigate the relationship between actual safety and perceived safety for cyclists. Furthermore, it identifies potential determinants of perceptions of traffic safety for cyclists, which have been identified in previous research. The second half of this chapter is dedicated to proposing a typology of unsignalized intersections for the Dutch context.

2.1 Perceived safety

In recent years there has been an increase in studies investigating perceived, rather than actual, traffic safety for cyclists (Ferenchak & Marshall, 2020; Lawson et al., 2013; Manton et al., 2016). According to many of these studies, perceived safety is interesting because it is often the most important barrier to cycling activity (Ferenchak & Marshall, 2020; Heinen & Hany, 2012; Pucher & Dijkstra, 2000). In a recent study in Vienna for example, 43% of respondents indicated that safety concerns kept them from cycling (Yannis & Cohen, 2016). Deery (1999) uses the term traffic risk perception to refer to interpretation of risk or danger associated with a traffic situation. Manton et al. (2016) explain that not actual risk, but perceived risk plays the most important role in determining behavior. Perceived traffic safety for cyclists is discussed under a wide variety of terms in the literature, including perceived risk, level of comfort and level of stress (Manton et al., 2016; Lanis et al., 1997). These terms all refer to the experiences of the cyclist in traffic. In this thesis the term perceived safety will be used to indicate the level of safety or comfort that is experienced by cyclists. Studies related to perceived safety usually aim to find out what factors make certain types of infrastructure attractive for cyclists (Carter et al., 2007). These studies are however very often limited to for example comparing on-road cycling infrastructure (bicycle lanes) to separate, off-road, cycling infrastructure (bicycle paths).

2.1.1 Actual safety and perceived safety

Heinen et al. (2010) make a distinction between objective safety and subjective safety. Objective safety, or actual safety, is the real safety experienced by cyclists, measured in incidents per inhabitants or per kilometers cycled. Subjective safety, or perceived safety, refers to how individuals experience safety. The relation between actual traffic safety and perceived traffic safety is subject to much debate in the literature. According to Landis et al. (2003), the correlation between actual and perceived safety is yet to be proven. Other studies have started to deliver evidence for such correlation, for example by Carter et al. (2007). They created a model that found many similarities in the factors that influence both perceived safety and actual safety. Their model will be elaborated on in section 2.2.3. Another example comes from a 2014 study of drivers' risk perceptions. Here participants were asked to rate their perception of risk while watching videos of traffic from the driver's perspective. The results showed great consistency between the participants' perceived risk and the calculated actual risk (Charlton et al., 2014). There is however not yet enough evidence to suggest that perceived and actual safety correlate. Both the study by Carter (2007) and the one by Charlton et al. (2014) also found inconsistencies between the outcomes of actual and perceived safety and risk.

Evidence does suggest however, that improving actual safety for cyclists does tend to have a positive effect on the perceptions of safety. Studies have shown that the risk of injury is significantly greater while cycling than it is while driving (Zegeer, 1994). This increased risk influences attitudes towards cycling. Pucher & Buehler (2008) found that the Netherlands is one of the safest countries for cyclists, leading the Dutch to not perceive cycling nearly as dangerous as compared to North-Americans. Policy in the Netherlands has promoted cycling safety intensely since the rise of environmental concerns in the 1970s, leading to cycling fatalities declining by over 70% (Pucher & Buehler, 2008). This decline in fatalities was accompanied by an increase in cycling, illustrating that improving actual traffic safety for cyclists has a positive effect on improving perceptions of safety. Perceived and actual cycling safety often go hand in hand, but there are also exceptions. Therefore, it is important to make the distinction between the two.

2.1.2 Differences in perceptions of safety

There is a range of external factors that have been found to influence risk or safety perceptions for road users. Individuals' perceptions of risk have been found to be significantly influenced by demographic characteristics such as age and gender (Wang & Akar, 2018). Nordfjærn & Rundmo (2009) found that male respondents perceive lower levels of risk for a variety of traffic situations than female respondents. This difference in level of safety perception based on gender is confirmed by most of the literature (Dejoy, 1992; Rundmo & Iversen, 2004). Another important factor that has been cited as a reason for differences in safety perception is age. One study found for example that adolescent males reported lower levels of risk perception as opposed to middle aged males when assessing photographs of traffic situations (Sivak et al., 1989). A third demographic characteristic that is often investigated in relation to traffic safety perceptions is level of education. This relationship, however, is less strongly established in the literature (Nordfjærn & Rundmo 2009). A finding that might also be relevant for the context of this MSc thesis project is differences in safety perception between cultural contexts. A recent study compared perceptions of risk for traffic situations between Ghanian and Norwegian respondents

(Nordfjærn & Rundmo (2009). Ghanian respondents were found to perceive traffic risks higher than Norwegian respondents. These findings indicate a relation between cultural context and perceptions of safety.

2.1.3 Vulnerable cyclists

Much of the research in the field of traffic safety has been looking at vulnerable road users (Silla et al., 2017). Vulnerable road users include pedestrians and cyclists, but also motorcyclists, as they have the highest risk of injury upon collision. Among cyclists however, there are also differences in level of vulnerability. Here vulnerability will be used in relation to the perceptions of safety and comfort experienced by cyclists. A vulnerable cyclist feels less safe and comfortable than the average cyclist, indicated by lower levels of perceived safety. The previous section has explored that demographic factors like gender and age often play a role in determining safety perceptions. Therefore, vulnerability in cyclists is in large part determined by such demographic characteristics, in combination with levels of skill or experience. Geller (2007) proposes a typology of cyclists, according to skill and attitudes towards cycling, in order to differentiate between more and less vulnerable cyclists. This typology includes the four types; ‘strong & fearless’, ‘enthused & confident’, ‘interested but concerned’ and ‘no way no how'. The ‘strong and fearless’ category are the most skilled and comfortable cyclists, including no more than 1% of the population. ‘Enthused & confident’ cyclists are quite comfortable sharing the road with motorized traffic, but prefer separate cycling infrastructure and make up about 7% of the population. ‘Interested but concerned’ cyclists would like to cycle regularly, but are often concerned for their traffic safety. This category is represented by some 60% of the population. Finally, the ‘no way no how’ category refers to those unable or unwilling to cycle and includes about 30% of the population (Geller, 2007). Geller’s classification of cyclists forms a basis for many traffic safety models, including the LTS, which will be discussed in section 2.2.1. According to Wang & Akar (2018) a classification of the population according to levels of skill and risk perceptions has been shown to lead to better infrastructure investments by identifying traffic situations not suitable for vulnerable users. This categorization however is based on research in the United States, where cycling is a less common mode of transport than in the Netherlands. There have not been any studies applying this typology to the Dutch context, but it is safe to assume that in the Netherlands a greater portion of the population would fit into the ‘strong & fearless’ and ‘enthused & confident’ categories. Because this classification cannot directly be applied to the Dutch context the present MSc thesis project will only make a distinction between two groups of cyclists; vulnerable and non-vulnerable cyclists.

2.1.4 Dutch context

The Netherlands is one of the safest countries for cyclists (Schepers et al., 2017). This fact is often attributed to the quality of cycling infrastructure in the country (Silla et al., 2017). The Dutch government provides cycling facilities, bicycle parking facilities and tries to promote bicycle commuting (Heinen & Handy, 2012). Another factor that plays a role, however, is the strong cycling culture. The popularity of cycling as a mode of transport results in relatively high average levels of skill for cyclists and in awareness in other road users (Engbers et al., 2018). This strong cycling culture means that most Dutch cyclists are generally skilled and comfortable in traffic. Therefore, they would be categorized in the first two levels of cycling skill as discussed in the previous section (Geller, 2007). There is however also a significant part of the population for whom this is not the case. We have seen that factors such as gender, age and cultural background play a role in determining perceptions of safety and therefore on vulnerability (Nordfjærn & Rundmo, 2009; Sivak et al., 1989). Primarily children and the elderly are often discussed as the most vulnerable groups of cyclists (Ferenchak & Marshall, 2020). Furthermore, international students, who are not as familiar with cycling, are another group that could be more vulnerable. This is especially an interesting group in a city like Groningen, where they form a significant part of the population (5.2%, Groningen City Monitor, 2020).

2.2 Models on perceived safety

The international literature on perceived traffic and cycling safety has produced a great variety of models that explain different levels of perceived safety by looking at roadway design and other contextual factors. Only a few of these models, like the BLOS and BCI, have seen wider application among practitioners. Furthermore, most of the newer models have yet to be tested more thoroughly. This section is dedicated to exploring the most relevant of these models in order to gain insight into what factors could influence perceptions of cycling safety. The focus of most of the academic models is on infrastructure design, as insights here are most interesting for planning practitioners trying to promote cycling through improving perceived safety.

2.2.1 Perceived safety on road segments

The Bicycle Level of Service (BLOS) and Bicycle Compatibility Index (BCI) are two influential models that address perceived safety of road segments for cyclists (Landis et al., 2003). They have been adopted by many States' Departments of Transportation in the USA as tools to assess the perceived safety and levels of comfort on road segments. These early models use the terms level of comfort, hazard and perceived safety interchangeably (Landis et al, 1997).

The Bicycle Level Of Service (BLOS) model is based on a study of cyclists' perceptions of hazard or safety (Landis et al., 1997). These perceptions reflect roadway segments' 'level-of-service'. This level-of-service was compared to a range of characteristics of the road. This study found the separation of bicycle and motorized traffic lanes with a stripe, number of total traffic lanes and the quality of the pavement, to be the most significant factors in determining level of service of a roadway segment (Landis et al., 1997).

The Bicycle Compatibility Index (BCI) also models the level-of-service associated with road segments (Harkey et al., 1998). This model was developed in the context of bicycle stress level literature, a concept introduced by Sorton and Walsh (1994). Bicycle stress level categorizes road segments in order of stress they produce for the cyclist. The BCI research by Harkey et al. (1998) investigated the relation between high levels of stress and factors that potentially play a role in influencing it. This study identified curb lane width, presence of a bicycle lane, traffic speed and volume to be the main determinants of cyclists' levels of stress (Harkey et al., 1998).

Another influential, more recent, model is the Level of Traffic Stress (LTS) model (Mekuria et al., 2012). The authors rightfully criticize LOS and BCI approaches for relying on data on traffic volume and road width, which is often not easily obtainable. The LTS classifies roads in one of four categories: LTS1 through LTS4. The levels relate to the types of cyclists that can deal with the corresponding levels of stress, based on the typology of cyclists by Geller (2007). These types of cyclists are: strong & fearless (LTS4), enthused & confident (LTS3), interested but concerned (LTS2) and no way, no how (LTS1). The application of these four categories allows the LTS model to not have to depend on too specific data. The model only uses the variables of traffic speed and lane width in assigning its classification, in addition to bicycle lane blockage (Mekuria, 2012). The strength of the LTS approach is that it requires little data input in comparison to the other approaches, making it easier to use (Ferenchack & Marshall, 2020).

The models discussed in this section relate cyclists' experience to the conditions of road segments in order to gain insight into what types of infrastructure relate to higher levels of perceived safety. The models have identified traffic speed, traffic volume, quality of the pavement, separation of motorized and non-motorized traffic (bicycle lane) and curb-lane width as factors influencing perceived safety for cyclists.

2.2.2 Perceived safety on intersections

The models discussed in the previous section, although interesting for identifying potential factors that affect perceived safety for cyclists, are not related to intersections, but to road segments. Therefore, Landis et al. (2003) developed a similar model for intersections, called the Intersection LOS (level-of-service) for bicycle through movement. The intersection LOS examines the level of comfort or safety experienced by cyclists while crossing an intersection. Participants were asked to rate their perception of safety after riding through a signalized intersection. Correlation analysis showed traffic volume, width of the outside lane and intersection crossing distance to be the most important factors in determining perceived safety. In this study, the presence of a bicycle lane was found to be less important on intersections.

Earlier, Davis (1987) had developed the Bicycle Safety Index Rating (BSIR), which included a model for calculating safety for cyclists on intersections. This model calculates safety as a function of traffic volume and geometric factors like the presence of through lanes, left-turn lanes, right-turn lanes and even curb radii and sight distances. Davis' (1987) BSIR model found a significant role for traffic volume, traffic speed and curblane width, in determining perceptions of safety for cyclists at intersections.

The LTS model, which has been discussed previously, can also be applied to intersections specifically. According to Mekuria et al. (2012), signalized intersections offer no additional traffic stress whereas unsignalized intersections do. However, the LTS model includes only the speed limit and the width of the street being crossed, as factors that influence traffic stress and therefore perceived safety (Mekuria et al., 2012). This model is therefore not as tailored to intersections as some of the other models that are discussed.

The Intersection Safety Index (ISI) is another model that investigates perceived safety for cyclists at intersections. In their research, Carter et al. (2007) looked at both perceived safety and actual safety for cyclists on intersections. Their model uses the number of crashes, conflicts and avoidance maneuvers, as well as safety ratings in order to assess an intersection's safety for cyclists. Carter et al. (2007) developed both a behavioral model (based on avoidance maneuvers) and a ratings model (based on perceived safety). They found that both models had variables in common, including: traffic volume, speed limit, traffic control and on-street parking. These variables therefore play a role in determining both perceived safety and actual safety. The similarities in these two models also provide further evidence for the relation between perceived and actual safety.

The Intersection models give some more insight into the factors influencing perceived safety for cyclists on intersections. The significant role of traffic volume, traffic speed, bicycle lanes, quality of the pavement and lane width has been found to apply, not only to roadway segments, but to intersections as well. Furthermore, crossing distance, curb radii, and traffic control measures (road markings) are found to be determinants for perceived safety on intersections specifically. The factors that are found to affect perceptions of safety for cyclists in the discussed models are summarized below in Table 2.1. It has become apparent that only few influential studies focus on investigating perceived safety on unsignalized intersections specifically. The LOS model, for example, was developed for signalized intersections only (Landis et al., 2003). This is striking since research has shown that the primary barrier to cycling is the high perceived levels of risk and danger (Pucher & Buehler, 2008). This perceived risk and danger is found to be most prevalent in unsignalized intersections, where most traffic accidents involving cyclists occur (Carter et al., 2007; Manton et al., 2016). Mekuria et al. (2012) even argue that signalized intersections offer no additional traffic stress for cyclists.

	Street segment / intersection	Year	Identified factors
BLOS	street segment	1997	separation of bicycle and motorized traffic, total traffic lanes, quality of the pavement
BCI	street segment	1998	curb lane width, presence of a bicycle lane, traffic speed, traffic volume
LTS	both	2012	traffic speed, lane width, crossing distance
Intersection LOS	intersection	2003	traffic volume, curblane width, crossing distance
BSIR	intersection	1987	traffic volume, traffic speed and curblane width
ISI	intersection	2007	traffic volume, traffic speed, traffic control, on-street parking

Table 2.1: Factors found to affect perceived safety for cyclists in previous models

2.3 Further research into perceptions of safety

The models discussed in the previous section have mostly been developed in attempts by researchers to provide tools for decision-makers and planners. There is however a wider range of academic literature that seeks to discover determinants for perceptions of safety for cyclists. Many of these studies find similar factors that influence safety perceptions. Foster et al. (2015), in a study into the role of bicycling facilities on perceptions of safety for cyclists in North-America, confirm that the presence of separate bicycling facilities improves safety perceptions. Some other studies however also identify factors that have not been investigated in the popular models. Recent studies have shown bicyclist crossing markings and crossing islands (refuge islands) for example to also play an important role in determining safety perceptions for cyclists on intersections (Reynolds et al., 2009; Wang & Akar, 2018). The presence of these bicycle crossing markings has been found to decrease the speed of motorized traffic, leading to higher levels of perceived safety. Similarly, case study research in the Netherlands, Denmark and Germany found speed bumps to improve safety perceptions for cyclists through reducing the speed of motorized traffic (Pucher & Buehler, 2008).

Another measure that has been shown to improve safety perceptions is using colored surfaces on intersections (Hunter et al., 2000). This measure was first introduced in Denmark in 1981 and has gained popularity in other countries as well. It exists in many forms; sometimes the entire intersection surface is colored and sometimes only some parts were motorized and non-motorized forms of traffic could conflict. The colors used range from blue (the original color from Denmark) to yellow and red (Jensen, 2008). Similar to marked cyclist crossings, they indicate the presence of a potential point of conflict to the motorized traffic. The presence of crosswalks has also been found to have the effect of slowing down traffic when positioned near intersections (Wang & Akar, 2018). Since pedestrians always have right-of-way here, the motorized traffic is likely to slow down and be more alert in their approach towards the intersection. In their study of intersection design and safety perceptions Wang & Akar (2018) found the presence of crosswalks near intersections to positively affect safety perceptions for cyclists on these intersections.

2.4 Factors influencing perceptions of safety

The factors that have previously been found to influence safety perceptions for cyclists can be divided into three main categories. First involves the general traffic conditions of the traffic situation. The second category involves individual cyclists' characteristics such as skill, experience and demographic characteristics. The final category includes factors related to infrastructural design. Since infrastructural design and traffic regulating measures are the main object of this MSc thesis project these are the most interesting.

2.4.1 Traffic conditions

Most of the models and studies discussed in the previous section have shown a relationship between perceived safety for cyclists and traffic volumes and traffic speeds. Specifically, higher volumes and higher speed limits for adjacent motorized traffic relate to lower perceptions of safety for cyclists (i.e. Carter et al., 2007; Harkey et al., 1997; Lawson et al., 2013). Traffic volume is of limited importance to this Msc thesis project, as it is not influenced by the design of intersections directly. Rather, traffic volumes are influenced by larger scale changes in the infrastructure network. The role of traffic volumes in perceived safety for cyclists on intersections is therefore beyond the scope of this MSc thesis project. Traffic speed however, relates more directly to the design of intersections and can be influenced more easily in general. Speed limits can be reduced at specific sections of road, like around intersections, as a safety measure. Traffic speed is not an infrastructure design-related factor. It will however still be included in the present study, since traffic speed can easily be changed by adjusting speed limits or through various design elements. Such design elements include speed-bumps and raised intersections.

2.4.2 Individual characteristics

The personal characteristics of individual cyclists also play an important role in their perceptions of safety. Individual characteristics can refer to both demographic characteristics or the cycling skill and experience of the cyclist. The classification of cyclists and corresponding models (LTS) shows how different types of cyclists experience different levels of comfort and safety (Geller, 2007; Mekuria et al., 2012). Geller’s four types of cyclists reflect how age and cycling skill are important determinants for safety perceptions. Other studies confirm the role of age, and identify gender as another determining factor (Dill et al., 2015). Furthermore, cycling experience has been shown to influence safety perceptions, with inexperienced cyclists being more likely to perceive traffic situations as dangerous (Bill et al., 2015). Wider societal norms also play an important role in influencing these individual characteristics. Heinen et al. (2010), for example, suggest that perceptions of safety are largely determined by attitudes and social norms. These are influenced by the Dutch cycling culture, which has previously been discussed as a reason for higher levels of cycling skill in the Netherlands. Investigating what individual characteristics influence perceptions of safety is interesting in identifying potentially vulnerable groups of cyclists in the Dutch context.

2.4.3 Infrastructure design

Arguably the most important factors that have been shown to influence perceptions of safety for cyclists on intersections relate to the design of infrastructure (Manton et al., 2016). It is commonly accepted that different types of infrastructure, and especially bicycle facilities, do not provide bicyclists with the same level of comfort or perceived safety (Ferenchak & Marshall, 2020). Much of the research in the field of perceived safety has looked at roadway and infrastructure design as a means to improve perceived safety (ie Carter et al., 2007; Mekuria et al., 2012). Previous studies suggest varying levels of effect for factors such as: the presence and type of cycling facilities (cycle lanes/ paths), curb lane width, number of traffic lanes, presence of parked cars, crossing distance, number of legs and intersection treatments (Carter et al., 2007; Landis et al., 1997; Lawson et al., 2013). All of the variables that will be investigated in this MSc thesis project are represented in Figure 2.1.

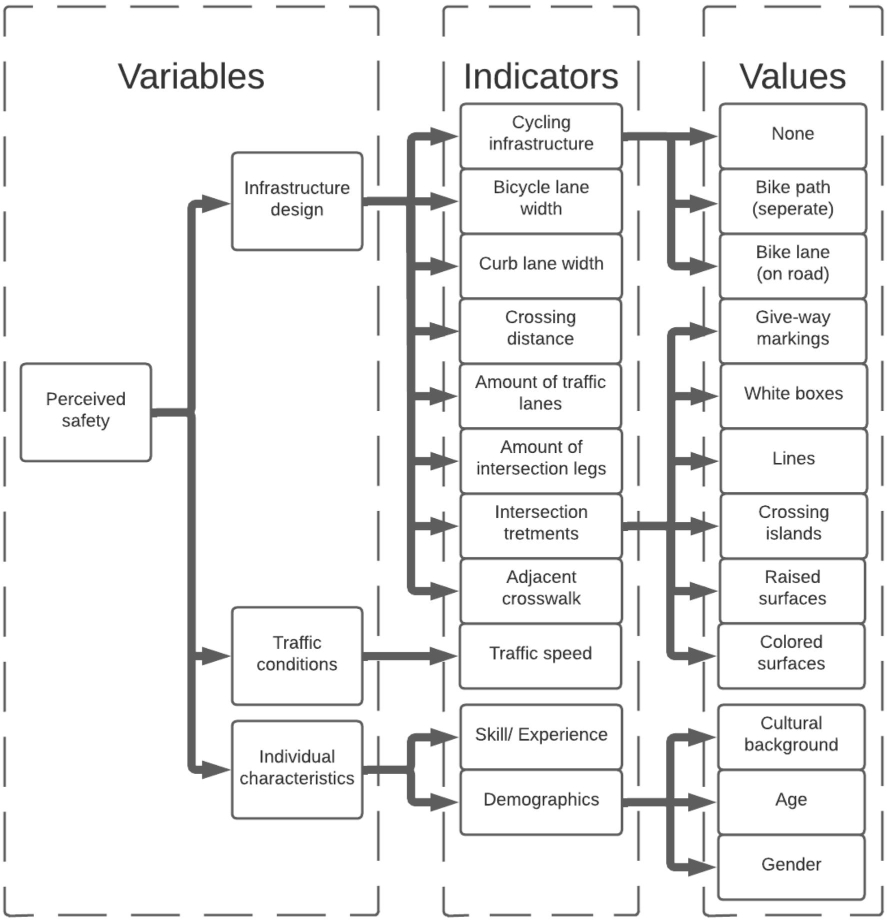

Figure 2.1: Factors influencing safety perceptions at intersections

2.4.4 Factors excluded from this study

Some of the factors that influence safety perceptions for cyclists on intersections that are identified by the literature are not included in this MSc thesis project. Most academic research into safety perceptions for cyclists has been carried out in North-America in attempts to promote cycling. Therefore, some variables do not carry the same relevance in this Msc thesis project. In the Netherlands the infrastructure is generally more adapted to cycling. One example is the quality of the pavement, which was identified as affecting safety perceptions for cyclists by Landis et al. (1997). This variable is not taken into account here, because differences in pavement quality in the Netherlands is limited. This is due to the fact that quality of the pavement is already a point of focus in Dutch infrastructure design (CROW, 2017). Furthermore, the general quality of Dutch road quality is consistently ranked among the best in the world (World Economic Forum, 2018; Statista, 2022). Traffic volume is another factor that has been identified in the literature that will not be taken into account in this MSc thesis project. Firstly, the effects of traffic volume on perceived safety have been confirmed by nearly all studies discussed, and are widely accepted (Carter et al., 2007; Harkey et al., 1998; Landis et al., 2003; Mekuria et al., 2012). Therefore there is no need for additional testing of its relation to safety perceptions. Second, this MSc thesis project is focused on design characteristics of intersections, not the traffic conditions. So despite the fact that traffic volumes are expected to have an effect on safety perceptions for cyclists, it will not be examined as it is beyond the scope of this thesis project.

2.5 Towards a typology of intersections

Not all intersections are similar enough to justify comparison. For example, the present thesis project discusses unsignalized intersections exclusively. Furthermore, roundabouts are also excluded for their unique differences from regular intersections. In order to carry out comparisons it is useful to construct a typology of intersections. Such a typology would allow for the identification of intersections that share enough similarities to justify a comparison. Such a typology has recently been proposed by the Salt Lake City department of transportation (2021). However, the Salt Lake City DOT's intersection typology cannot be applied to the Dutch context as such, and will therefore have to be adapted. This is because of differences in the design of infrastructure between the American and Dutch contexts.

2.5.1 Road types

The main variable that determines an intersections' type in the Salt Lake city DOT's typology, is what types of streets intersect. This will also be the starting point for a typology for the Dutch context. The Salt Lake City DOT identifies three types of road levels: major, medium and local roads. These are comparable with the Dutch, stroomwegen (through-roads), gebiedsontsluitingswegen (distributor roads) and erftoegangswegen (access roads) (Schepers et al., 2017; SWOV, 2021). Since this MSc thesis project is focused on perceived cyclist safety within the urban environment, only the latter two will be examined. This is because the major level roads in the Netherlands (through-roads) only serve motorized traffic. The Dutch classification of roads is based on a hierarchical structure where motorized traffic only mixes with non-motorized traffic on roads with a low speed limit (Schepers et al., 2017). Access roads are the most local level roads in the Netherlands, where a speed limit of 30 or 50km/h is usually in place. Access roads are a place where motorized and non-motorized traffic are allowed to mix, in most cases there are no separate bicycle facilities. These roads will be referred to as local roads. The second type, distributor roads are roads that serve medium-distance traffic. Within the built environment, these roads usually have a speed limit of 50 or 70 km/h. The general policy aim in the Netherlands is to facilitate cyclists on these distributor roads with a bicycle path or lane. This is however not always the case. Gebiedsontsluitingswegen will from here on be referred to as medium roads.

2.5.2 Typology of intersections

By definition an intersection involves the interaction by at least two streets. Street type largely determines the design of the infrastructure of said road, and therefore also the design of its intersections. The first classification of the intersections is thus based upon the types of streets intersecting. Within the urban environment there are three broad types: local-local (type 1), local-medium (type 2) or medium-medium (Type 3). Within these three types of intersection an additional distinction is made, according to the relation between cyclists and motorized traffic. This distinction based on presence and type of cycling infrastructure is chosen because it is often cited as the most important determinant of safety perceptions (Carter et al., 2007; Foster et al., 2015; Harkey et al., 1998; Landis et al., 1997). A third and final distinction is made in the classification of intersections, relating to the difference between continued and interrupted bicycling facilities. In intersections between two medium roads (type 3) some bicycle lanes continue across the intersection, whereas some do not. This usually has to do with whether the road with a bicycle path has right-of-way. The distinction seems minor, but it might be significant as a result of the difference in visibility. The final classification includes six types of intersections as represented in Table 2.2.

Street	Intersection type	Cycling facilities
local-local	type 1	no separated bicycle lane
local-medium	type 2 a	no separated bicycle lane
	type 2 b	continued separate bicycle lane
medium-medium	type 3 a	no separated bicycle lane
	type 3 b	continued separate bicycle lane
	type 3 c	interrupted separate bicycle lane

Table 2.2: Overview of the proposed intersection typology

Intersection type 1

The first type of intersection is between two local level streets, which is referred to as an equal intersection. The usual rules of the road apply and there are no additional traffic regulating measures. Type 1 does not have any subtypes since local roads are never accompanied by separate cycling infrastructure. This type of intersection is mostly found in places where little traffic comes through, such as residential areas, as well as parts of the city-center. An example of a type 1 intersection is given below in Figure 2.2, illustrated by a picture from Google Streetview and a top-down schematic.

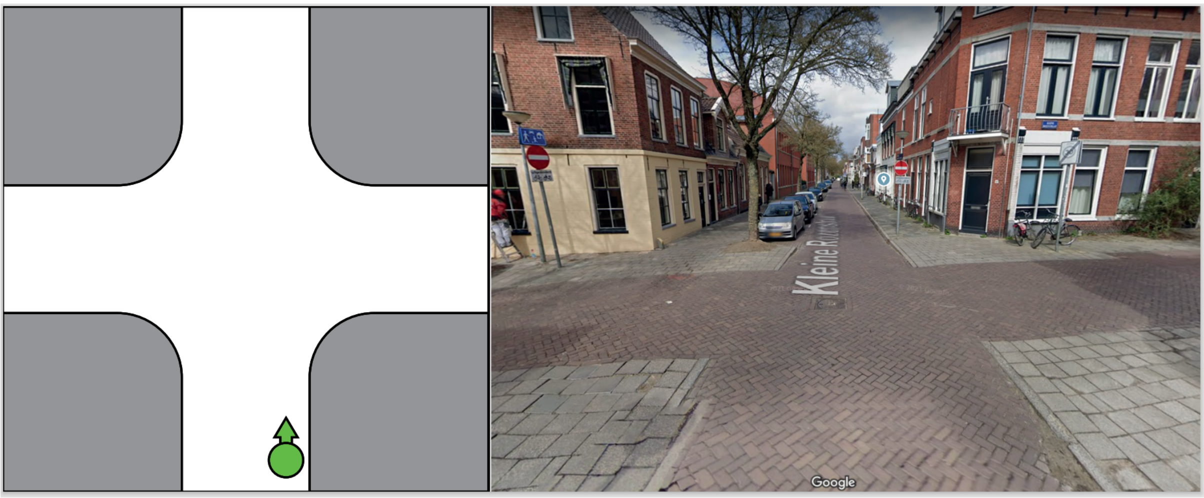

Figure 2.2: Example of type type 1 intersection (Case 35), left:illustration, source: author; right: image, source: Google Streetview

Intersection type 2a

The second type is an intersection between a local and medium road, referred to as intersection with exit (from Dutch kruising met uitrit). In this type of intersection, there is no separated bicycle lane on the medium road. The medium road alway has right-of-way, which is indicated by a raised surface on the local street, right where it meets the medium street (CROW, 2013). This raised surface is referred to as an uitrit, it signals that the driver on the street with the uitrit has to give way. An example of a type 2a intersection is given below in Figure 2.3, illustrated by a picture from Google Street View and a top-down schematic.

Figure 2.3: Example of a type 2a intersection (Case 6), left:illustration, source: author; right: image, source: Google Streetview

Intersection type 2b

The third type of intersection is still between a local and medium road, however here the medium road is accompanied by a bicycle lane. Usually there is still an uitrit (raised surface) present on the local road, where it meets the medium road. Again, the general rule is that the medium road always has right of way. The difference with type 2a is solely in the fact that cyclists have their own designated bicycle lane, which is usually part of the surface of the medium road. In some cases however, the bicycle lane is separated from the road entirely. An example of a type 2b intersection is given below in Figure 2.4, illustrated by a picture from Google Street View and a top-down schematic.

Figure 2.4: Example of a type 2b intersection (Case 8), left:illustration, source: author; right: image, source: Google Streetview

Intersection type 3a

The fourth type of intersection is between two medium level roads, where one of the roads will have right-of-way, depending on the additional measures taken. Type 3a is the first of three types of intersections between two medium level roads. This type does not have any type of cycling infrastructure on either of the medium roads. It is mostly found outside the city-center, and is therefore adapted to more car-use than cycling. An example of a type 3a intersection is given below in Figure 2.5, illustrated by a picture from Google Street View and a top-down schematic.

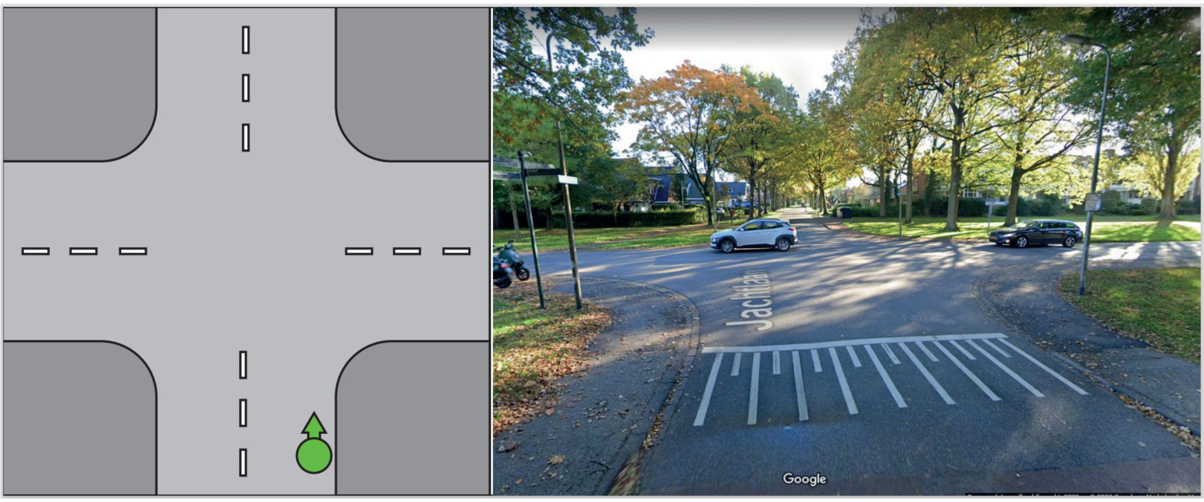

Figure 2.5: Example of a type 3a intersection (Case 97), left:illustration, source: author; right: image, source: Google Streetview

Intersection type 3b

Type 3b is the second type of intersection between two medium level roads. On this type of intersection, one of the medium roads has a continued separated bicycle lane. This means that the red coloured surface of the bicycle lane continues across the intersection. The medium road that has the continued bicycle lane always has right of way, and is therefore accompanied by a set of give-way road markings (sharks' teeth). An example of a type 3b intersection is given below in Figure 2.6, illustrated by a picture from Google Street View and a top-down schematic.

Figure 2.6: Example of a type 3b intersection (Case 26), left:illustration, source: author; right: image, source: Google Streetview

Intersection type 3c

The sixth and last type of intersection is also between two medium roads. This type of intersection distinguishes itself from the other medium-medium intersections in the fact that bicycle lanes are present, but do not continue across the intersection. Either one, or both, of the roads can have a seperate bicycle lane. The bicycle lanes do not continue across the intersection to signal that cyclists have to give way, a measure that is always combined with a set of give-way road markings (sharks' teeth). This combination of discontinuing the coloured surface with additional give-way signs is similar to in type 3b, but now the right of way is for the motorized traffic. An example of a type 3c intersection is given below in Figure 2.7, illustrated by a picture from Google Street View and a top-down schematic.

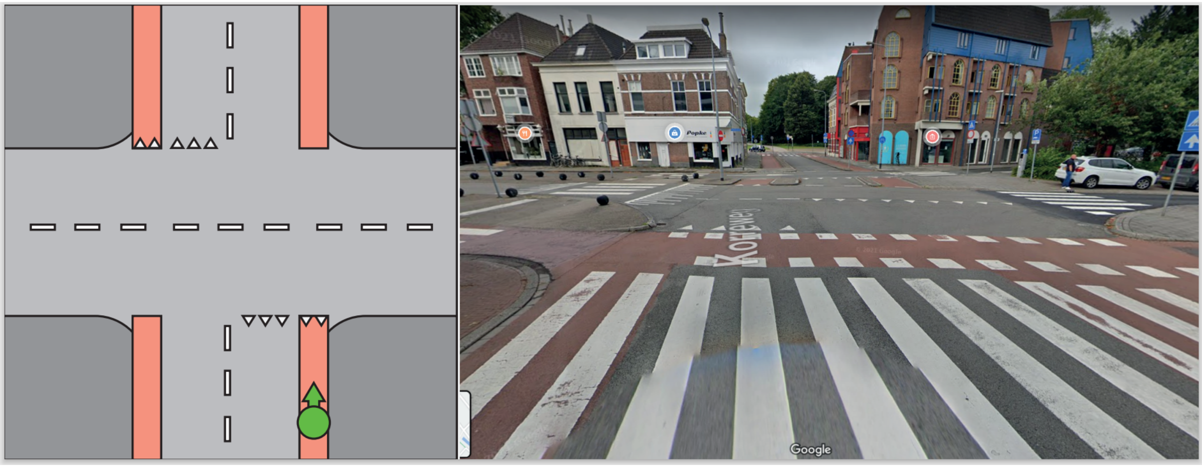

Figure 2.7: example of a type 3c intersection (Case 4), left: illustration, source: author; right: image, source: Google Streetview

2.6 Synthesis

The first half of this chapter has been dedicated to identifying factors that might play a role in determining safety perceptions for cyclists at intersections. An important role is expected for traffic speed, bicycle lanes, curb lane width, crossing distance and traffic control measures (road markings), based on previous models by Landis et al. (2003) and Carter et al. (2007). Further research has also suggested a role for crossing markings, crossing islands, colored surfaces and the presence of crosswalks adjacent to the intersection. On the other hand, individual characteristics are also found to affect perceptions of safety. These mostly relate to demographic factors such as gender and age. All of these factors will be investigated for their role in determining safety perceptions of cyclists in the Netherlands. The second half of this chapter has been dedicated to proposing a typology of intersections, to serve as a starting point for comparison between intersections. This typology is based on the level of streets that intersect, as well as the presence of cycling infrastructure.

3 Methodology

This chapter will elaborate on the methodology applied in the current MSc thesis project. The design of the project is based on previous studies conducted in the field of safety perceptions research (Carter et al., 2007; Landis et al., 2007; Ng et al., 2017). First, the chapter will provide insight in the selection process of a sample of 100 intersections that will be investigated. Second, the characteristics of these intersections that are to be evaluated will be discussed in detail. Third, the chapter will give an overview of the process of formulating and spreading an online survey that inquires into the perceptions of safety for cyclists at these intersections.

3.1 Case Selection

3.1.1 Data sources for case selection

The proposed typology of intersections has identified six types of intersections where motorized and non-motorized (cyclists) types of traffic mix. This is the starting point for selecting 100 intersections, in the municipality of Groningen, where perceived safety is investigated. Selection of the intersections under investigation is based on data regarding traffic accidents that involved at least one cyclist. For this purpose, the Bestand Geregistreerde Ongevallen Nederland 2018-2020 (BRON, translation: File Registered Accidents Netherlands), is used. This dataset is based on accidents that are registered to the police, combined with the Nationaal Wegenbestand (NWB, translation: National Roads Database). This data is made publicly available by the national government through Rijkswaterstaat and the Nationaal Georegister (Nationaal Georegister, 2021).

The choice was made to select intersections that have the most accidents involving at least one cyclist. These are the intersections that have the lowest actual safety for cyclists in the municipality of Groningen. They are therefore most likely to be accommodated by low levels of perceived safety. In order to find causes for low perceptions of safety it is necessary to select cases where low levels of perceived safety might occur. In order to identify these intersections that have low actual safety and therefore potentially low perceived safety the BRON and NWB datasets are analyzed in ArcGIS (ARCMAP version 10.8.1). First, both datasets are clipped to the municipal boundaries of Groningen. Second, only cases that involve a cyclist or an e-bike as either party in the accident are selected. Furthermore, accidents outside of intersections, that is on straight parts of the road, are also excluded. This procedure leaves us with 440 cases of traffic accidents on intersections that involve at least one cyclist in the municipality of Groningen. The locations of these accidents in the municipality of Groniningen are represented below in Figure 3.1. This involves both 3-legged and 4-legged intersections. Mopeds and other types of hybrid vehicles are also excluded. The BRON does not include a distinction between signalized and unsignalized intersections. Therefore the remaining cases still include crashes at signalized intersections.

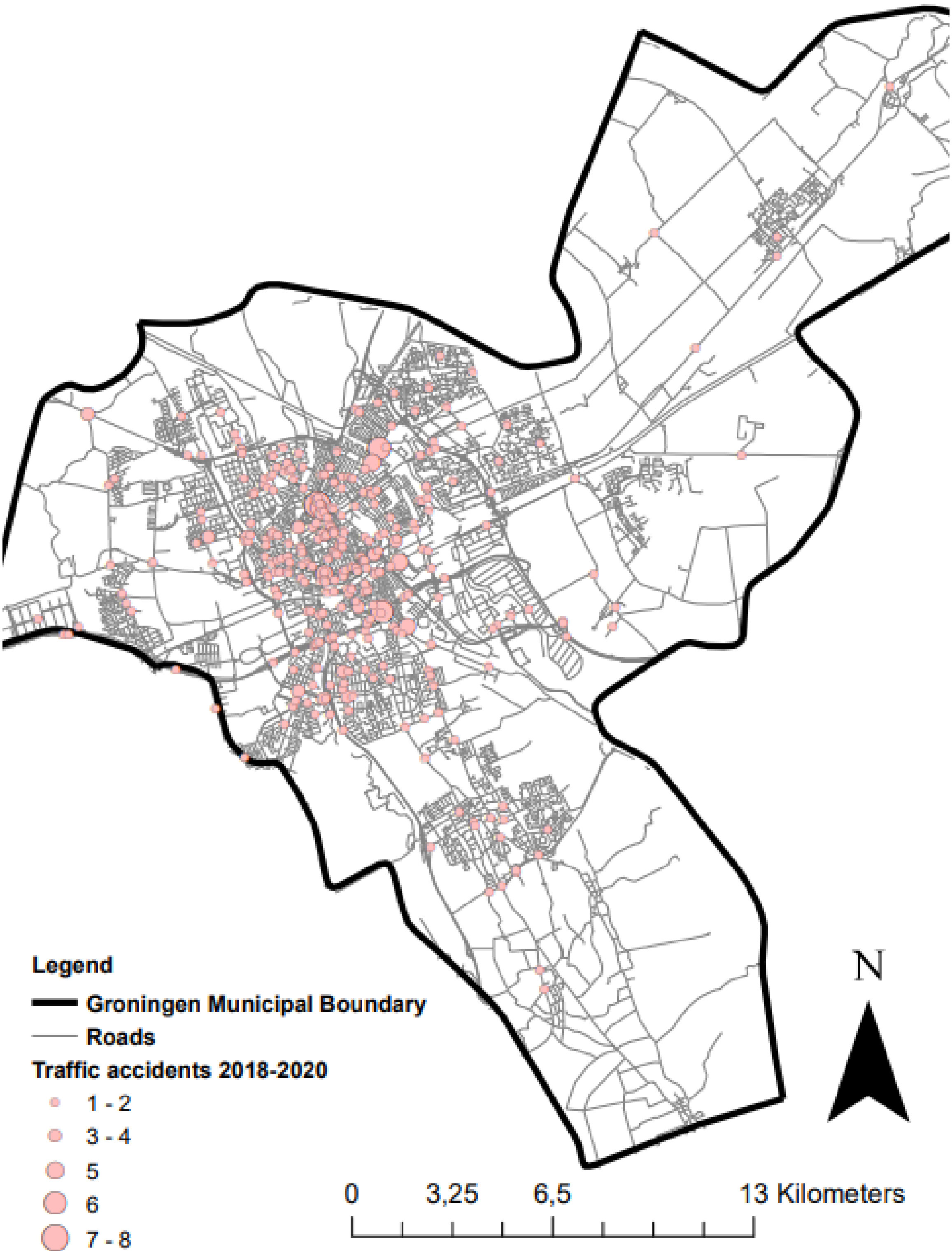

Figure 3.1: Traffic accidents on intersections involving at least one cyclist between 2018 and 2020 in the municipality of Groningen

3.1.2 Point density & hotspot analyses

This data was first analyzed spatially, using heat mapping tools based on both kernel density and point density (Figure 3.2). Kernel Density Estimation especially, is a tool regularly applied for point density analysis of traffic accidents in GIS (Kazmi et al., 2022; Prasannakumar et al., 2011). The resulting heat maps allow for the visualization of areas where many intersections have seen crashes involving cyclists. Both types of density analysis show similar patterns. This first visual analysis suggests that many intersections north of the city-center, near the Ebbingestraat and Korreweg are associated with low levels of actual safety for cyclists. These areas will therefore be investigated for selecting intersections.

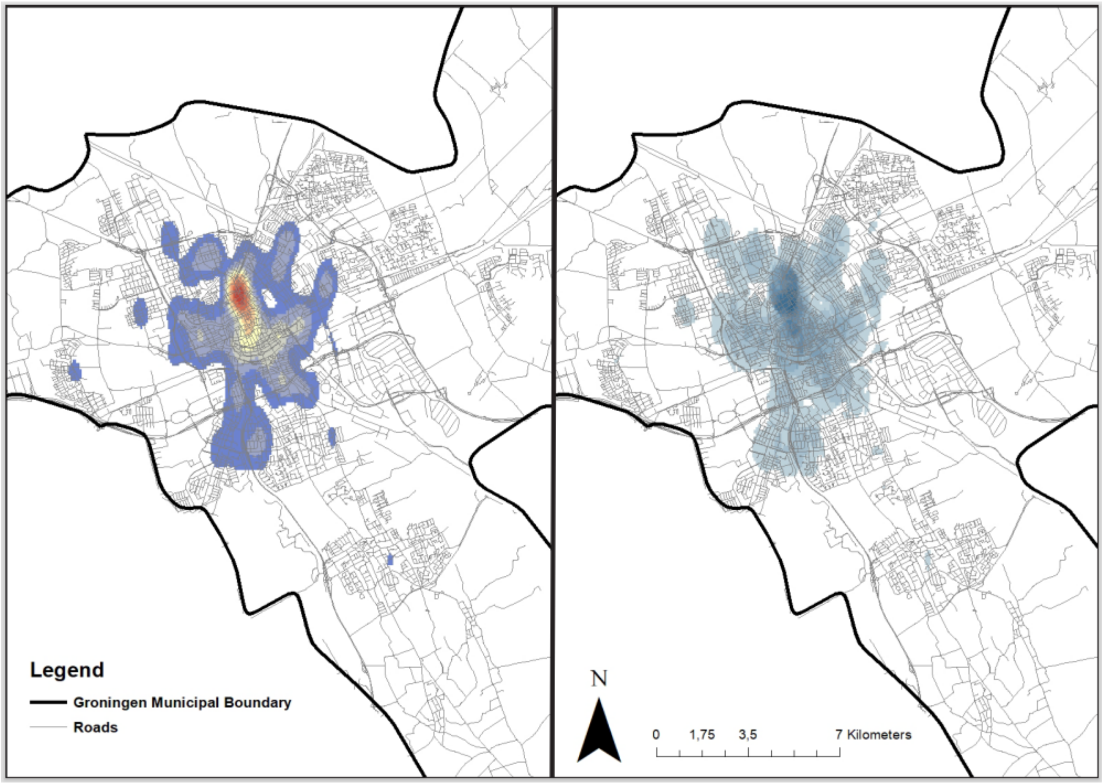

Figure 3.2: Left: kernel density heatmap, right: point density heatmap

Besides the spatial analysis of the kernel density and point density mapping tools, a spatial statistics tool was also applied to identify areas, and therefore intersections, where many accidents happened. The Getis-Ord Gi* hotspot analysis identifies statistically significant hotspots. In order to apply this spatial statistics test, the point data had to be transformed into weighted points based on the number of accidents for each intersection, using the collect events tool. The collect events tool creates a new layer that combines data points in the same location into one weighted point. The Getis-Ord GI* function is then used to carry out a cluster analysis (Prasannakumar, 2011). This hotspot analysis confirms patterns that are visualized by the kernel- and point- density heatmaps (Figure 3.3). Significant hotspots are confirmed around the Nieuwe Ebbingestraat, north of the city-center, as well as around the Korreweg in the northeast of the city. Some hotspots coincide with signalized intersections, like the one in the northwest, on the Friesestraatweg. These hotspots are not relevant for this MSc thesis project and will therefore not be reflected in the selected cases.

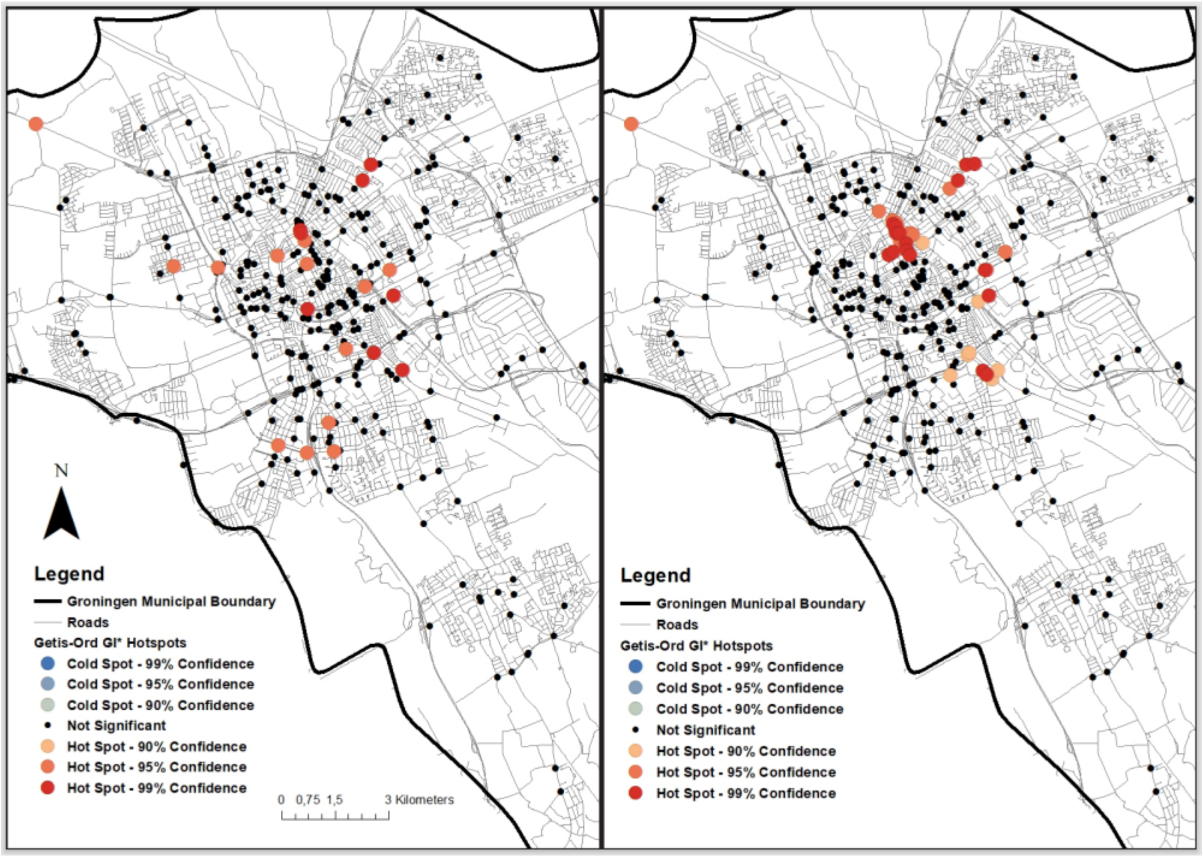

Figure 3.3: Left: Getis-Ord Gi hotspot analysis based on inverse distance; right: Getis-Ord Gi* hotspot analysis based on a fixed distance of 500*

3.1.3 Selected cases

The hotspots identified in ArcGis were all investigated to see if they were unsignalized and fit in the proposed typology (excluding roundabouts for example). Next, intersections that had seen at least one accident involving a cyclist and were located within high density areas on the heatmaps were investigated. Finally, additional intersections were selected that had at least seen one accident involving a cyclist. This process of selecting intersections resulted in a total of 100 cases. The cases are not spread equally across the six types of intersections. For some types, like 3a (7 cases), there were no more intersections that had seen a traffic accident involving a cyclist within the municipality of Groningen. These differences are due to the fact that some types of intersections are more common than others. The composition of intersection types among the selected intersections is represented below in Table 3.1. The case selection process is summarized in Figure 3.4.

Type of intersection	Number of cases
Type 1	19 intersections
Type 2a	22 intersections
Type 2b	24 intersections
Type 3a	7 intersections
Type 3b	16 intersections
Type 3c	12 intersections
Total	100 intersections

Table 3.1: Spread of the selected intersections over the six types

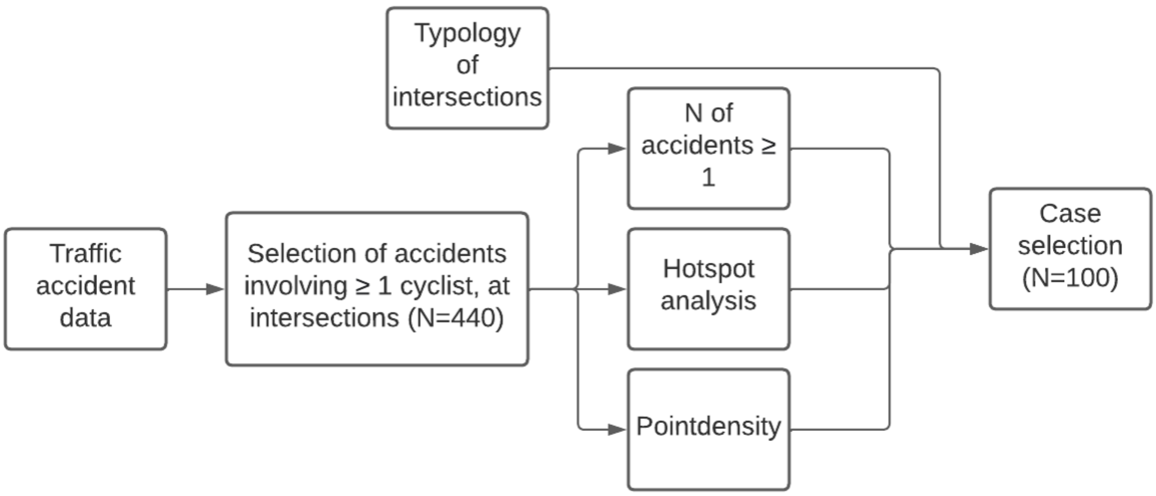

Figure 3.4: Summary of case selection process

3.2 Intersection Characteristics

Each selected intersection was evaluated on a number of predefined characteristics. The selection of these characteristics is based on common findings in the literature, as discussed in section 2.2 (i.e. Carter et al., 2007; Landis et al., 1997). This first selection of characteristics includes a broad selection of factors that potentially determine perceptions of safety. These characteristics include: amount of legs in the intersection, speed limit, amount of traffic lanes, presence and type of cycling infrastructure, curb lane width, crossing distance, presence of a crossing island for cyclists, presence of a crosswalk, type of road markings, the presence of raised surfaces and the presence of colored surfaces. The resulting dataset is included in Appendix 2. These characteristics will serve as independent variables in a regression model of perceived safety. The remainder of this section is dedicated to defining each of these characteristics.

3.2.1 Speed limit

The speed limit refers to the maximum speed for motorized traffic on the intersection. The standard speed limit within the built environment is 50km/h in the Netherlands (ANWB, 2022). For some streets, especially in the inner-city, this is lowered to 30km/h. Since all selected intersections are located in the built environment of the municipality of Groningen the speed limit varies between 30 and 50 km/h. The 30km/h limit is only found around type 1 intersections, however not all type 1 intersections have this limit. For some intersections the speed limits on the main street and the crossing street differ. This is often the case for type 2 intersections, where local and medium roads intersect. In these cases the higher value of 50km/h is taken into account, since motorized traffic is only signaled to lower their speed by a traffic sign after leaving the intersection. The sample includes 18 intersections with a speed limit of 30km/h and 82 intersections with a speed limit of 50km/h. According to previous research, traffic speed is one of the main determinants of perceived cycling safety on intersections (Harkey et al., 1998).

3.2.2 Number of intersection legs

The number of legs refers to the amount of streets or street sections that come together in an intersection. This MSc thesis project included three types: 3-legged, 4-legged and 5-legged intersections. The 100 selected intersections included 39 3-legged, 60 4-legged and one 5-legged intersection(s). The amount of legs of the intersection was previously examined by Wang & Akar (2018), but was not found to have a significant effect on safety perceptions. A higher amount of legs is hypothesized to negatively relate to perceived safety as each leg adds complexity to the intersection.

3.2.3 Bicycle lane/path width

Bicycle lane width refers to the width of the bicycle lane on which the cyclist crosses the intersection. This variable does not play a role in all cases, as some intersections do not have any bicycle lanes or paths. Furthermore it does not play a role in those intersections where the bicycle lane does not continue across the intersection.

3.2.4 Number of traffic lanes

Number of traffic lanes refers to the number of lanes on the main street, meaning lanes adjacent to the cyclist. The amount of traffic lanes varies little within the sample of selected intersections, since all intersections are located within the built environment. There are a total of 89 intersections with 2 lanes. This number includes roads where there is no clear separating line between traffic coming from opposite directions. There are 9 roads where there is just one traffic lane, meaning these are all one-way streets. Finally there are two intersections with four lane roads, both located around industrial areas at the south side of the city.

3.2.5 Curb lane width

The curb lane refers to the lane for motorized traffic that is adjacent to the curb or bicycle lane or path. Most cases only have one lane in each direction, this will still be referred to as the curb lane. In those cases where there are no bicycle facilities, cyclists also ride on the curb lane. In those cases where the bicycle path is separated from the curb lane, its width is not expected to affect perceived safety.

3.2.6 Presence and type of cycling infrastructure

Cycling infrastructure refers to the red-colored bicycle lanes and paths, as they are discussed in the typology for type 2b, 3b and 3c. The distinction is made between bicycle lanes, which are located on the same surface as the motorized traffic, and bicycle paths, which are separated from it by a curb, greenery or parking facilities (Schepers et al., 2017). The sample includes 39 intersections with bicycle lanes, 15 intersections with bicycle paths and 46 intersections without specific cycling facilities. Because these cycling facilities are of particular interest, another distinction is made. On the intersections where the cyclist on the bicycle path or lane has right-of-way, the colored surface of the bicycle path continues across the intersection. On intersections where the cyclist on the bicycle path or lane has to give way, the bicycle path or lane is interrupted. The sample includes 29 continued bicycle lanes and 10 interrupted bicycle lanes. Similarly, there are 8 continued bicycle paths and 7 interrupted bicycle paths. Research has shown that the presence of a bicycle lane or path at an intersection lowers the likelihood of a crash by 45% (Schepers et al., 2013). Furthermore the presence of a bicycle lane or path has previously been found to positively affect perceived safety as well (Foster et al., 2015; Harkey et al., 1998; Landis et al., 1997). Therefore, the presence of either type of bicycle path/lane is expected to have a positive effect on actual and perceived safety for cyclists.

3.2.7 Crossing distance

The crossing distance refers to the distance from the start to the end of the intersection. It has often been found to relate to lower levels of perceived safety (Carter et al., 2007; Landis et al., 2003). Crossing distances for intersections in the sample vary between 3.8 meters and 26.0 meters.

3.2.8 Crossing islands

The crossing island (or refuge island) is a very specific measure in intersection design. It is most often used when a pedestrian or bicycle path crosses a medium road. The crossing island allows for the crossing of traffic from one direction, then stopping and waiting on the crossing island before crossing traffic from the other direction. The crossing island is hypothesized to improve perceived safety by allowing not all lanes to have to be crossed at once. The sample includes a total of 11 intersections with crossing islands.

3.2.9 Road markings

Road markings are used to indicate who has right-of-way on an intersection. Furthermore they inform road users of potential conflict points with other road-users. The most common types at intersections are white boxes or lines to signal a bicycle crossing and give-way road markings. The sample includes 55 intersections with give-way road markings. White boxes that signal a bicycle crossing only exist in combination with a continued bicycle lane or path and give-way road markings. White lines that signal a bicycle crossing are used when a bicycle lane or path is interrupted. Therefore they are combined with a set of give-way road markings for the cyclists. The sample includes 23 intersections with white boxes and 11 intersections with white lines that signal bicycle crossings.

3.2.10 Raised surfaces

There are two types of raised surfaces associated with intersections. The first is where a whole intersection is raised slightly. This design is often accompanied by a differently colored surface across the whole intersection (in the sample red and yellow). This design is applied to signal to road users that they are approaching an intersection and to force them to slow down. The selected sample includes 6 instances of a raised intersection. The second type of raised surface is what is called an uitrit (exit) in Dutch. An uitrit is where the section of a road that is adjacent to the intersection is raised. This measure is mostly found when a smaller (local) road joins a larger (medium) road. Oftentimes the raised surface is a continuation of the larger roads' sidewalk. The uitrit signals that whoever crosses it has to give way to all other traffic, a function similar to the previously discussed give-way road markings. The selected sample includes 26 intersections with one exit and 11 intersections with two exits.

3.2.11 Colored surfaces

Colored surfaces are used as measures to raise awareness of the fact that the intersection is a potential point of conflict. Usually the entire intersection is painted a different color from the rest of the streets. The sample includes six cases where the intersection is colored, mostly yellow or red. Previous findings suggest a positive impact on perceptions of safety for cyclists (Hunter et al., 2000).

3.2.12 Pedestrian crossings

Pedestrian crossings refer to the broad white stripes on the street surface that signal right-of-way for any pedestrians crossing there. They are often located around intersections, because streets intersect not only with each other, but also with each other's sidewalks. Pedestrian crossing adjacent to intersections have previously been found to positively affect perceptions of safety for cyclists (Wang & Akar, 2018). The selection includes 28 intersections with one adjacent pedestrian crossing, 10 with 2 adjacent crossings and 4 with 3 adjacent crossings.

3.3 Survey

3.3.1 Survey Design

An online survey was used to gather data for cyclists' perceptions of safety on the 100 selected intersections. This survey was designed using Qualtrics, an online survey tool. The survey took between 7 and 9 minutes to complete. The survey was split in two parts, with the first part including general questions about the participants' demographics and cycling background. These include questions about age, gender, place of origin, regularity of cycling, and self-reported cycling skill. Only close-ended questions were included in the survey. The survey was available in both Dutch and English, both versions are included in Appendix 5.

The second part of the survey shows the respondent a selection of 12 out of the 100 intersections under study. This number was chosen based on the length of the survey after two rounds of trials. Including more scenarios in the survey would have increased the average completion time to near 10 minutes, which would have had a negative impact on response and completion rates. The Qualtrics online survey tool allows for randomization of the questions, meaning that each respondent sees a random selection of intersections from the sample. Each intersection is represented by a Google Streetview image (Appendix 3), as well as a top-down schematic (Appendix 4). Most of the images are taken from the perspective of the cyclist approaching the intersection (Figure 3.5). In some cases this was not possible, here the image shows a different angle and the cyclist's approach in the scenario is represented by a green arrow (Figure 3.6). All of the schematics also included a green arrow to show the crossing direction. Respondents were instructed to assume crossing the intersection straight ahead, or if this wasn't possible, to take a left-turn. The respondents were then asked to rate their perceived level of safety on a 5-point likert scale, as is most common in this type of research (Carter et al., 2007; Landis et al., 2003; Ng et al., 2017).

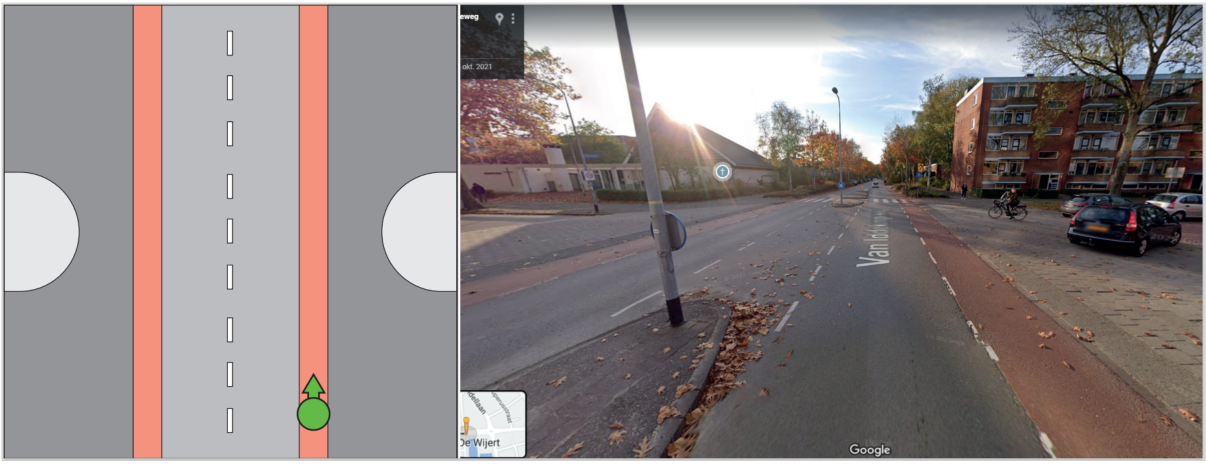

Figure 3.5: Example of intersection represented from cyclists' perspective (case 19)

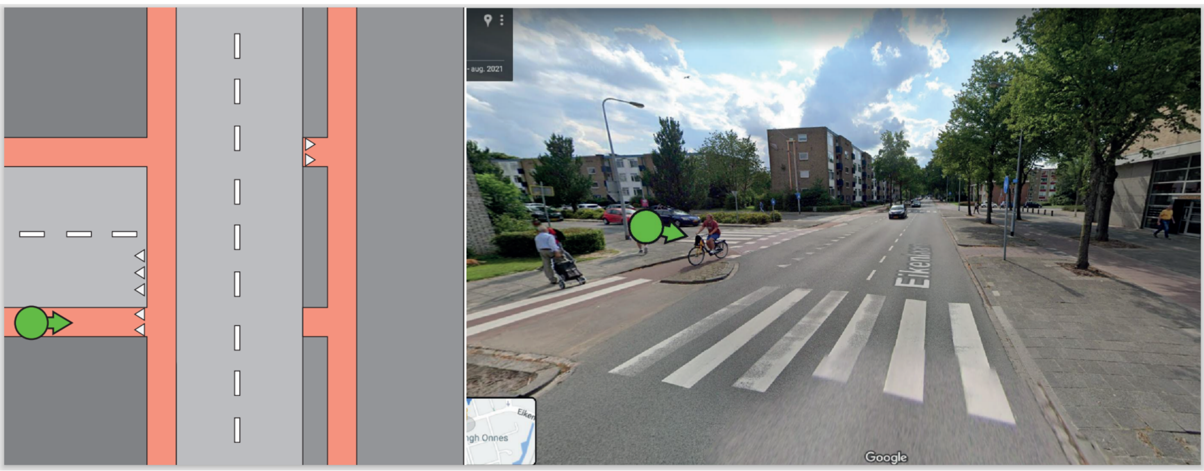

Figure 3.6: Example of intersection represented from the side (case 25)

3.3.2 Survey Response

The online survey was spread through contacting cycling clubs and unions, as well as institutions that promote cycling and traffic safety. As a result, the survey was posted on multiple websites, blogs, newsletters and social media accounts. It was for example included in the newsletter of the Fietsersbond Groningen (cyclist union), which is a union that represents the interests of cyclists. The Fietsersbond Groningen was contacted by email in April 2022, resulting in the online survey being included in their newsletter of May 2022. The fora where the survey was posted included: Fietsersbond forum, Wereldfietser and Wegenforum, which all relate to traffic safety and cycling. Furthermore, the survey was spread among the researchers' personal contacts, within the university and outside of it. Both a QR-code and direct URL to the survey were included in such efforts for collecting responses. The online survey ran between May 6 and June 7, 2022. Over this period a total of 344 responses were recorded.

3.4 Synthesis

This section gave a description of the methodology that was applied in this MSc thesis project. A total of 100 intersections were selected based on data regarding traffic accidents involving cyclists. Next, these intersections were assessed on a list of 15 characteristics that are hypothesized to influence safety perceptions. An online survey of 344 responses provided insight into the perceptions of traffic safety for cyclists at these intersections.

4 Results

This chapter will report on the statistical testing that is applied to two different datasets. The first dataset includes all 100 intersections, their characteristics and their average (mean) level of perceived safety. This mean level of perceived safety is based on survey responses. The second dataset is the output of the online survey, including data on demographics, as well as perceptions of cycling safety for each intersection in the sample. This chapter is structured according to the research questions. Sections 4.3 through 4.5 relate to research question 1, 2 and 3 respectively. A general description of the data follows first.

4.1 Data description

A total of 344 responses to the online survey were recorded. Of these responses, 28 were not included in the analysis due to being incomplete and two more responses were excluded due to being aged under 18 years. Any responses that completed one or more scenarios were included in the analyses, leaving a total of 314 eligible responses. Most participants were male (64%), aged between 19 and 34 years (36%) and originating from the Netherlands (91%). Furthermore, most participants have lived in the Netherlands for more than 5 years and cycle 5 to 7 times a week. The majority of the sample reports their cycling skill as totally skilled (71%) and their perceptions of overall cycling safety as safe (56%). The sample characteristics are summarized below in Table 4.1.

Variable	N	%
Gender		
Male	**201**	**64,0%**
Female	**107**	**34,1%**
Non-binary/prefer not to say	**6**	**1,9%**
Age		
19-34	**115**	**36,6%**
35-44	**23**	**7,3%**
45-54	**37**	**11,8%**
55-64	**77**	**24,5%**
65+	**62**	**19,7%**
Cultural background		
Netherlands	**286**	**91,1%**
Europe	**19**	**6,1%**
Outside Europe	**9**	**2,9%**
Self reported cycling skill		
totally skilled	**224**	**71,3%**
skilled	**82**	**26,1%**

somewhat skilled	**5**	**1,6%**
not very skilled	**2**	**0,6%**
not skilled	**1**	**0,3%**
Self-reported perception of cycling safety		
very safe	**85**	**27,1%**
safe	**177**	**56,4%**
somewhat safe	**41**	**13,1%**
quite unsafe	**9**	**2,9%**
very unsafe	**2**	**0,6%**

Table 4.1: Sample characteristics (N=314)

4.2 Safety Perceptions

The online survey presented respondents with a random set of 12 out of the 100 intersections. A portion of the respondents not completing all 12 scenarios has caused some differences in the number of responses per case. The response rate per case varies between 29 and 38 responses. One case (case 58) only had 29 responses, it will still be included in the analyses however, as this is not far off the minimum standard of 30 responses. Variables such as perceived safety, self-reported cycling skill and self-reported perception of cycling safety are recorded in the survey on a 5-point Likert scale. These variables will be treated as interval variables, meaning that we assume directionality and even spacing between them. Perceptions of safety recorded on a Likert scale are treated as interval variables in most of the safety perceptions research (Ng et al., 2017). Therefore, we can use these variables in nonparametric tests that compare means such as independent samples t-tests and analyses of variance. Individual perceptions of safety were used to calculate an average level of perceived safety for each intersection. Mean levels of perceived safety are expressed as a number between 0 and 4, where 0 is associated with the lowest possible level of perceived safety and 4 is associated with the highest possible level of perceived safety. The levels of perceived safety of the 100 selected intersections range between 1,28 and 3,37 (Appendix 2). An alpha level of 0.05 was used for all statistical tests.

4.3 What types of intersections are perceived as unsafe

An analysis of variance was conducted in order to investigate what types of intersections are associated with higher levels of perceived safety. Here the dependent variable is mean level perceived safety and the independent variable is intersection type. The first analysis of variance was used to investigate differences between the three main types of unsignalized intersections. Type 1 intersections had an average level of perceived safety of 2.54 (*SD*=0.35); type 2 intersections had an average level of perceived safety of 2.50 (*SD*=0.38), and type 3 intersections had an average level of perceived safety of 2.33 (*SD*=0.35). Therefore, no significant difference in mean perceived levels of safety between intersection types was indicated, $F(2,97)=2.890$, $p=0.060$. The means and standard deviations per intersections type are represented below in Table 4.2.

	N	Mean	Std. Deviation	Minimum	Maximum
type 1	19	2.54	0.080	2.03	3.37
type 2	46	2.50	0.056	1.67	3.30
type 3	35	2.33	0.060	1.28	2.89
total	100	2.45	0.037	1.28	3.37

Table 4.2: Mean levels of perceived safety per intersection type

Next, differences in mean levels of perceived safety between type 2a and type 2b intersections were investigated. Here an independent sample t-test was applied since there are two categories, which both follow a normal distribution. This t-test indicated a significant difference in mean level of perceived safety between type 2a ($M=2.26$, $SD=0.28$) and type 2b ($M=2.73$, $SD=0.32$) intersections, $t(44)=-5.312$, $p=0.000$. Therefore, the type 2b intersections are perceived as significantly more safe. The means and standard deviations per intersections type are represented below in Table 4.3.

Type	N	Mean	Std. Deviation
Type 2a	22	2.26	0.282
Type 2b	24	2.73	0.318

Table 4.3: Mean levels of perceived safety for type 2a and 2b

Mean levels of perceived safety were also investigated within type 3. Here a nonparametric test was used, since mean levels of perceived safety are not normally distributed within type 3a. This Kruskal-Wallis test did find a statistically significant difference in mean levels of perceived safety between type 3a (mean rank=15.00), 3b (mean rank=25.78) and 3c (mean rank=9.38), $H(2)=18.336$, $p=0.000$. The mean ranks are summarized below in Table 4.4. A pairwise post hoc Dunn's test reveals that significant differences exist in mean rank levels of perceived safety between type 3b and 3a (p=0.020) and between type 3b and 3c (p=0.000). Other pairwise comparisons were not significant. Therefore, type 3b intersections are associated with higher levels of perceived safety than type 3a or 3c.

Type	N	Mean Rank
Type 3a	7	15.00
Type 3b	16	25.78
Type 3c	12	9.38
Total	35	

Table 4.4: Mean rank of perceived safety for type 3a, 3b and 3c

4.4 Intersection characteristics corresponding with high levels of perceived safety

A linear regression model was used to investigate the relationship between individual intersection characteristics and perceived safety at unsignalized intersections. The dependent variable used was the mean level of perceived safety for each intersection, as derived from the survey data. The regression included the independent variables as discussed in section 3.2 and listed below in Table 4.5. The linear regression went through an iterative process in order to determine how variables were to be included. Some variables were categorized or coded differently after initial analysis, in order to satisfy the assumptions of linear regression modeling. Speed limit was changed from a ratio into a two-level variable, since all intersections were located in either 30km/h or 50km/h zones. The variable bicycle lane width was removed entirely as it was only applicable for cases where a bicycle lane was present.

These variables significantly predicted perceived safety, $F(19,80)=5.375$, p=0,000 and $R^2=0.561$.

The multiple linear regression model was:

*Perceived Safety = 2.204 - (0.107*speed) - (0.021*bike lane) - (0.019 bicycle path) + (0.511* continued bicycle lane/path) - (0.133*give-way markings) - (0.114*lines) - (0.022*raised intersection) - (0.300* crossing island) - (0.073*colored surface) - (0.063*crosswalk) + (0.051*three legged) - (0.337*five legged) + (0.111*two lanes) - (0.839*four lanes) - (0.002*curbalne width) + (0.021*crossing distance) + (0.196* two-way).*

The variables “four legged”, “one lane” and “one way'' were excluded from the model as they were collinear with the variables “three legged”, “two lane” and “two way” respectively. The presence of a continued bicycle lane or path was found to significantly predict safety perceptions (β=0.662, p=0.000). The presence of a crossing island was also found to significantly predict safety perceptions (β=-0.253, p=0.012). It was also found that the presence of four lanes significantly predicts safety perceptions (β=-.317, p=0.000). Finally, crossing distance was found to significantly predict safety perceptions (β=0.238, p=0.041). The rest of the variables did not significantly predict safety perceptions.

Variable name	Code	Values	Variable name	Code	Values
Perceived Safety	Dependent variable		Crosswalk	0	no
				1	yes
Speed	0	30km/h	Crossing distance	0 - 26.0 m	
	1	50km/h			
Bicycle lane	0	no	Curb lane width	0 - 5.7 m	
	1	yes			
Bicycle path	0	no	3-legged	0	no
	1	yes		1	yes
Continued bicycle lane	0	no	4-legged	0	no
	1	yes		1	yes
Give-way markings	0	no	5-legged	0	no
	1	yes		1	yes
White boxes	0	no	one lane	0	no
	1	yes		1	yes
Lines indicating bicycle crossing	0	no	two lanes	0	no
	1	yes		1	yes
Uitrit	0	no	four lanes	0	no
	1	yes		1	yes
Raised intersection	0	no	one way	0	no
	1	yes		1	yes
Crossing island	0	no	two way	0	no
	1	yes		1	yes
Colored surface	0	no			
	1	yes			

Table 4.5: Variables included in linear regression analysis

4.5 Differences in safety perceptions for vulnerable road users

4.5.1 Gender

Individual characteristics like gender and age are often found to have a significant effect on perceptions of safety. Here we will examine if such a relationship holds true in the municipality of Groningen. First, the safety perceptions between males and females were compared. An independent samples t-test showed no significant difference in self-reported perceived safety of cycling based between males (*M*=3.13, *SD*=0.69) and females (*M*=2.99, *SD*=0.81), t(306)= -1.683, p=0.102. The means and standard deviations are summarized below in Table 4.6.

Gender	N	Mean	Std. Deviation
Female	107	2.99	0.807
Male	201	3.13	0.691

Table 4.6: Mean self-reported perception of cycling safety by gender

Another independent sample t-test did indicate a statistically significant difference in self-reported cycling skill between males (*M*=3.75, *SD*=0.48) and females (*M*=3.56, *SD*=0.70), *t*(159.325)=-2,512, *p*=0.013. Therefore, men are found to rate their level cycling skill higher than women do. The means and standard deviations are summarized below in Table 4.7.

Gender	N	Mean	Std. Deviation
Female	107	3.56	0.703
Male	201	3.75	0.477

Table 4.7: Mean self-reported level of cycling skill by gender

4.5.2 Age

Secondly, self-reported perception of cycling safety was compared between groups based on age. An analysis of variance showed significant differences between age groups, *F*(4.309)=5.088, *p*=0.001. A pairwise post hoc Tukey's test revealed a significant difference between the groups 19-34 (*M*=3.25, *SD*=0.80) and 55-64 (*M*=2.83, *SD*=0.72), p=0.001. This test also revealed a significant difference between 19-34 (*M*=3.25, *SD*=0.80) and 65+ (*M*=2.89, *SD*=0.79), *p*=0,016. The age groups of 55-64 and 65+ therefore have a significantly lower mean self-reported perception of cycling safety, as compared to the 19-34 group. The means and standard deviations are summarized below in Table 4.8.

Age group	N	Mean	Std Deviation
19-34	115	3.25	0.804
35-44	23	3.17	0.491
45-54	37	3.19	0.569
55-64	77	2.83	0.715
65+	62	2.89	0.791
Total	314	3.06	0.756

Table 4.8: Mean self-reported perception of cycling safety by age group

Another analysis of variance was used to investigate the relation between self-reported cycling skill and age. This test did indicate statistically significant differences between age groups, $F(4.309)=2.927$, $p=0.021$. However, a pairwise post hoc Tukey's test only showed a significant difference between the 45-54 and the 65+ groups ($p=0.020$). Therefore, the 45-54 group has a significantly higher self-reported level of cycling skill as opposed to the 65+ group. The means and standard deviations are summarized below in Table 4.9.

Age group	N	Mean	Std Deviation
19-34	115	3.68	0.615
35-44	23	3.52	0.947
45-54	37	3.89	0.315
55-64	77	3.73	0.448
65+	62	3.53	0.535
Total	314	3.86	0.573

Table 4.9: Mean self-reported level of cycling skill by age group

4.5.3 Cultural background

Next, self-reported perception of cycling safety was compared between Dutch natives and non-Dutch natives that have lived in the Netherlands for less than a year. Here a nonparametric test was used since the number of non-Dutch respondents was only 28 and there was no normal distribution within either population. This Mann-Whitney test indicated a statistically significant difference in self-reported perception of cycling safety mean rank between Dutch natives (mean rank=160.93) and non-Dutch natives (mean rank=122.48), $U=3023.500$, $Z=-2.393$, $p=0.017$. We can therefore conclude that Dutch natives have a significantly higher self-reported perception of cycling safety than non-Dutch natives. The mean ranks are summarized below in Table 4.10.

Cultural Background	N	Mean Rank	Sum of Ranks
Dutch	286	160.93	46025.50
Non-Dutch	28	122.48	3429.50
Total	314		

Table 4.10: Mean rank of self-reported perception of cycling safety by cultural background

Finally, the relationship between cultural background and self-reported cycling skill was explored, also using a Mann-Whitney test as self-reported cycling skill was not normally distributed in either population. This Mann-Whitney test indicated a statistically significant difference in mean rank self-reported cycling skill between Dutch (mean rank=163.68) and non-Dutch (mean rank=94.39) cyclists, U=2237.000, Z=-4.898, p=0.000. Therefore, Dutch cyclists report their cycling skill significantly higher, as opposed to non-Dutch cyclists in the Netherlands. The mean ranks are summarized below in Table 4.11.

Cultural Background	N	Mean Rank	Sum of Ranks
Dutch	286	163.68	46812.00
Non-Dutch	28	94.39	2643.00
Total	314		

Table 4.11: Mean rank of self-reported cycling skill by cultural background

4.6 Synthesis

This chapter provided a description of the output of the statistical analyses. First, differences in perceived safety between types of intersections were tested using an ANOVA, a t-tests and a Kruskal-Wallis test. Secondly, linear regression was applied to create a model of characteristics that determine perceptions of safety. Finally, a variety of parametric and nonparametric tests was applied in investigating the relationship between perceptions of safety and demographic characteristics. Results will further be discussed with respect to the corresponding literature in the next Chapter.

5 Discussion

This chapter aims to provide a discussion of the results of the statistical analyses reported in Chapter 4. This chapter will follow a similar structure as the previous chapter by relating the subsections to the three research questions.

5.1 Types of intersections (RQ1)

The first part of the research was focused on comparing between intersections types. The main goal here was to identify whether differences in perceived safety could be found between types, and whether these could be attributed to the type of streets and/or the type of cycling facilities. The first comparison between types of intersections was intended to identify types of unsignalized intersections with low levels of perceived safety for cyclists. Interestingly no significant differences were found between type 1, type 2 and type 3 intersections. Here, the expectation was to find differences, because the different types of intersections relate to different street types.

Previous research has suggested a role for traffic speeds, volumes and numbers of lanes in affecting perceptions of traffic safety (Carter et al., 2007; Landis et al., 2003). Since medium streets are associated with higher speeds, volumes and more lanes, type 2 and 3 intersections would be expected to relate to lower levels of perceived safety. This finding indicates that the types of streets that intersect are not the most important predictor for safety perceptions. This is a positive outcome in the sense that road types could not be changed easily. Meaning that if type 1 intersections (local-local) were perceived as safer than type 3 intersections (medium-medium), it would not be possible to change type 3 intersections into type 1 intersections.

Within type 2 intersections a second comparison was applied to investigate the role of cycling infrastructure on safety perceptions on unsignalized intersections. This comparison between type 2a and 2b intersections revealed significant differences between the two. Type 2b intersections, which include a continued bicycle lane or path, were found to relate to higher levels of perceived safety. The type 2a and type 2b intersections are represented by their illustrations below in Figure 5.1. Because the difference between type 2a and 2b intersections relates to the presence of cycling infrastructure, this finding suggests that cycling infrastructure plays a role in determining perceptions of cycling safety. This finding would be in line with expectations based on previous studies (Foster et al., 2015; Harkey et al., 1998; Landis et al., 1997).

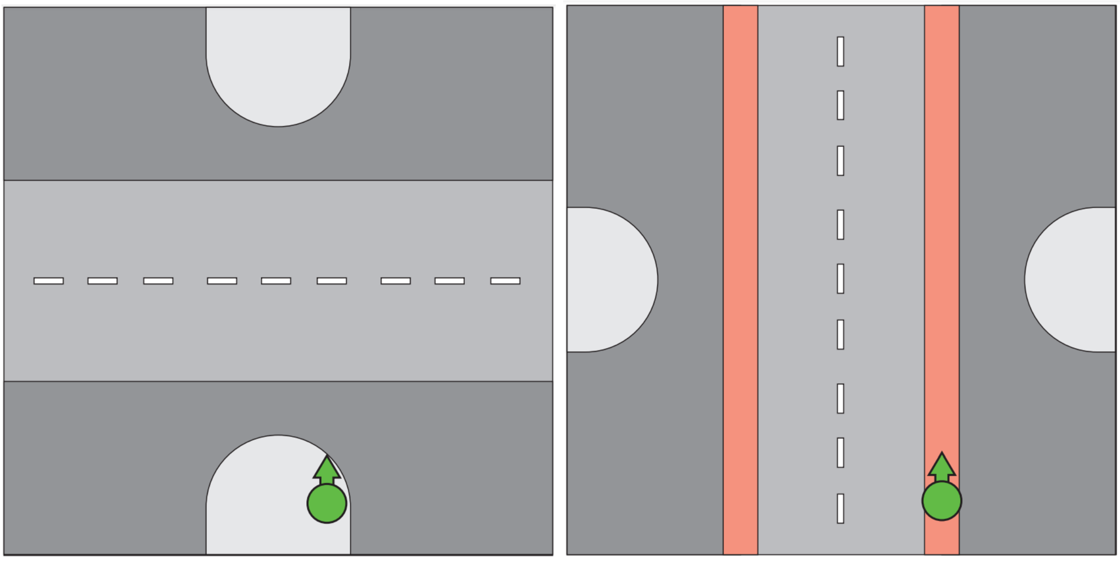

Figure 5.1: left: type 2a intersection, right: type 2b intersection

The third comparison looked at differences between type 3a, 3b and 3c intersections. Here type 3b intersections were found to be perceived as significantly safer than both type 3a and type 3c intersections. Therefore, within both type 2 and type 3 the intersections with continued bicycle facilities were found to be perceived as safest. These findings again suggest that cycling facilities that continue across an intersection improve perceived safety for cyclists on that intersection. No significant difference was found between type 3a and type 3c intersections. Type 3a, type 3b and type 3c intersections are represented by their illustrations below in Figure 5.2.

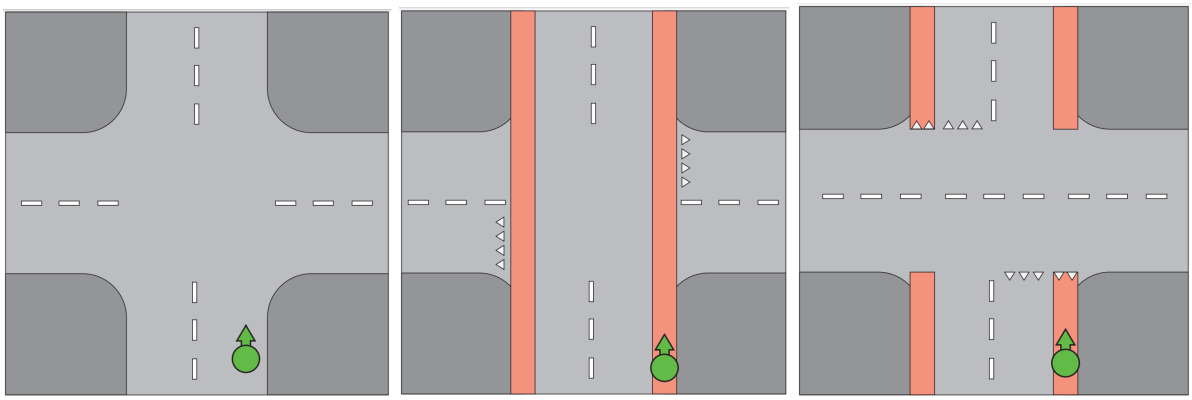

Figure 5.2: left: type 3a intersection, middle: type 3a intersection, right: type 3c intersection

5.2 Intersection characteristics (RQ2)

The comparisons between intersection types suggest that the presence and type of cycling infrastructure plays an important role in determining perceptions of cycling safety at intersections. Further examination into the roles of individual intersection characteristics confirmed this finding. Specifically, continued cycling facilities were found to be the main determinant for perceptions of safety for cyclists at intersections in Groningen. Both the comparison between intersection types and the regression modeling of intersection characteristics point to the presence of cycling facilities continuing across an intersection as the main determinant for perceptions of safety. As mentioned previously, this finding is supported by most of the previous literature (Carter et al., 2007). However, the presence of bicycle infrastructure is most often cited as determinant for safety perceptions in roadway segment models (Foster, 2015; Harkey et al., 1998; Landis et al., 1997). For roadway segments, the main danger for cyclists is the motorized traffic in the lanes adjacent to them, not intersecting them. Therefore such models show that bicycle paths are perceived as safer than bicycle lanes. This MSc thesis project did not find such a difference between bicycle lanes and bicycle paths for intersections, which is likely due to the fact that separation from the adjacent traffic lanes is not the main concern of cyclists on intersections. On unsignalized intersections, the main influence to safety perceptions is traffic on the intersecting street. The continuation of the red colored surface of the bicycle lane across the intersection serves perceived safety on intersections. There are two important reasons that likely explain this finding. First, cycling facilities across an intersection mean that the cyclist crossing this intersection has the right of way. In this way, such a continued bicycle path provides a clear hierarchy on the intersection. Secondly, these cycling facilities continuing across the intersection provide visibility, thereby making other road users aware of the potential conflict points on the intersection.

Strikingly, crossing distance was found to have a small but significant positive effect on perceived safety, meaning that larger crossing distances relate to higher levels of perceived safety. This finding is not in line with expectations based on the previous literature. The most important models on perceptions of safety for cyclists at intersections, the intersection LOS (level of service) and ISI (intersection safety index) models, both indicated a negative relationship between crossing distance and perceived safety (Carter et al., 2007; Landis et al., 2003). This negative relationship was explained by the fact that larger crossing distances mean that cyclists are exposed to motorized traffic on the crossing street for a longer time. One possible explanation for this finding that contradicts expectations, is the fact that intersections with a long crossing distance provide long sightlines and thereby good visibility. Visibility as a result of sight distance has previously been found to improve actual cycling safety and is likely to improve perceived safety (Abdur et al., 2021).

Another key finding is the negative relation between the presence of a crossing island (refuge island) and perceived safety for cyclists. A previous study by Wang & Akar (2018) also found this negative relation between the presence of crossing islands and safety perceptions. Their paper however, does not go into potential explanations for this phenomenon. One such potential explanation is the relation between the presence of such crossing islands and high traffic volumes and speeds. This relationship could however not be tested in this MSc thesis project as a result of the missing data on traffic volumes. The only other study that included the presence of crossing islands, did not find it to have a significant effect on perceptions of safety for cyclists (Carter et al., 2007).

The presence of 4 lanes was found to have a significant negative relation with perceived safety, meaning that more traffic lanes reduce perceptions of safety. This finding is in line with expectations based on previous literature (Carter et al., 2007; Landis et al., 2003; Landis et al. 1997). There was however no difference in safety perceptions between one and two lane roads, meaning that this relation only exists when the number of lanes becomes quite sizable. In the urban environment the most common solution is to make intersections on such wider roads signalized.

The most important models on perceptions of safety for cyclists at intersections, the intersection LOS (level of service) and ISI (intersection safety index) models, identified traffic volume, traffic speed and curb lane width as other main determinants for perceived safety (Carter et al., 2007; Landis et al., 2003). This MSc thesis project did not find a significant role for traffic speed and curb lane width. This is likely the result of the different ways in which motorized and non-motorized forms of traffic mix in the Netherlands as opposed to North-America. In the Netherlands cyclists never share the same road as motorized traffic when speed limits are above 50km/h. Therefore, Dutch cyclists do not have to deal with high-speed traffic on the curb lane. Furthermore, traffic volume was not investigated in this MSc thesis project. The reason is that this relation is examined in depth in previous studies and data on traffic volumes is not easily obtainable, which is also one of the main criticisms to the intersection LOS and ISI models.

Further studies into safety perceptions at intersections suggested a role for raised intersections, colored surfaces and adjacent crosswalks (Hunter et al., 2000; Reynolds et al., 2009; Wang & Akar, 2018). None of these intersection characteristics proved to have a significant effect on perceptions of safety in this MSc thesis project. This is potentially the result of their low frequencies of occurrence in the sample of intersections. Colored surfaces for example were only present at 6 intersections in the sample, raised intersections were present at 7. For other characteristics this was not necessarily the case (adjacent crosswalks = 45 cases). Characteristics that did not occur often in the sample might be investigated further, which will be discussed in the suggestions for further research.

5.3 Individual characteristics (RQ3)

The second part of the research investigated the role of individual cyclists' characteristics on their perceptions of safety in order to identify vulnerable groups of cyclists in the Dutch context. Previous research, mostly conducted in North-America, suggested differences in perceptions of safety between groups based on gender and age. Because of the unique Dutch cycling culture the difference between Dutch cyclists and non-Dutch cyclists living in the Netherlands was also investigated. Firstly, gender was found not to affect perceptions of safety in the Dutch context. Males did self-assess their cycling skill higher as opposed to females. This did however not lead to any difference in safety perceptions. The expectation from the literature was to find differences based on gender, because males are often found to have higher perceptions of safety as opposed to females (Ferenchack & Marshall, 2020; Nordfjærn & Rundmo, 2009; Sivak et al., 1989; Wang & Akar, 2018). The absence of such a difference based on gender in the Netherlands is likely the result of the high frequency of cycling trips of both males and females (over 65% cycles 5-7 times a week).

Significant differences were however found between age groups. The 55-64 and 65+ groups were found to have the lower perceptions of safety, as opposed to the 19-34 group. This finding confirms the expectation that higher age relates to lower safety perceptions (Ferenchack & Marshall, 2020; Nordfjærn & Rundmo, 2009). Older cyclists can therefore be classified as vulnerable in the Dutch context. Based on the literature, children were also expected to belong to this group (Ferenchak & Marshall, 2020), however this hypothesis was not tested in this MSc thesis project since the online survey was directed at adults (18+) only.

Finally, a difference in safety perceptions between Dutch and non-Dutch cyclists was found. Non-Dutch cyclists in the Netherlands were found to perceive cycling as less safe, as opposed to Dutch cyclists. Nordfjærn & Rundmo (2009) were the first to examine and find significant differences in perception of cycling safety between different cultural backgrounds. This MSc thesis project confirms their findings within the Dutch context. The role of cultural background has been considered in the MSc thesis project since the Municipality of Groningen has a sizable group of international residents. Dutch cyclists were however also found to self-assess their cycling skill as higher, as opposed to non-Dutch cyclists. It is therefore likely that part of this difference in perceived safety is attributed to differences in cycling experience and skill. Nonetheless, the non-Dutch cyclists, mostly consisting of international students, also belong within the classification of vulnerable cyclists in the Netherlands.

The literature on different types of cyclists identified the elderly to be most likely to be included in the most vulnerable group of cyclists, like the ‘no way no how’ group from Geller’s (2007) classification (Dill & McNeil, 2016). This body of work also found females to be more likely to be included in this vulnerable category, as opposed to males. The most interesting finding in terms of the relation between individual demographic characteristics and perceptions of safety in this MSc thesis project is therefore the fact that females in the Netherlands are not more vulnerable cyclists than males are.

When considering vulnerable cyclists, the focus should primarily be on the elderly population. The elderly are the most interesting group of vulnerable cyclists, since previous research has shown that ageing limits the exercise of autonomy and independence (Snowdon, 2002). A large part of this autonomy for elderly people relates to mobility. Low perceptions of cycling safety among elderly people form a barrier to cycling, thereby adding to these limitations of their mobility (Manton et al., 2016). The pressure competence model by Lawton and Nahemow (1973), emphasizes that individual skills and competences reduce as age advances, leading to a restriction on their mobility. This model argues that the behavior of the elderly is the result of the interaction between their competences and environmental pressures (Albuquerque et al., 2018). In this context, perceptions of danger while cycling can be a large environmental pressure. This is where spatial planning has a role in facilitating a transport- and infrastructure system that has the ability to accommodate cycling among the elderly. By taking into account the perceptions of cycling safety of the elderly population, the planning practitioner has the ability to give them some degree of mobility and, by extent, autonomy. This could be done by arranging intersections in such a way that they are perceived as safe by elderly cyclists. This MSc thesis project has taken a first step in identifying what factors influence such perceptions of safety at unsignalized intersections in the Dutch context. However, further research into the subject would be necessary to gain full insight into what factors influence perceptions of safety for elderly cyclists in particular. This point will be discussed in more detail in the next chapter.

6 Conclusion

This MSc thesis project aims to identify the factors that affect perceptions of safety at unsignalized intersections for cyclists in the Netherlands. It has done so by evaluating perceptions of safety at 100 intersections in the municipality of Groningen. To strengthen the evaluation of these intersections a typology of intersections is proposed based on street types and bicycling facilities.

6.1 Answering the research questions

RQ1: What types of intersections are perceived as safe and unsafe by cyclists?

It was found that the type 2b and type 3b intersections are perceived as the safest. The type 2b intersection is an intersection between a medium and local road, where separate cycling infrastructure is present across the intersection along the medium road. The type 3b intersection is an intersection between two medium level roads, where separate cycling infrastructure is present across the intersection along one of the roads. Most notable about this finding is the fact that both intersections that are perceived as the safest include cycling infrastructure continued across the intersection. On such intersections with continued cycling facilities, the cyclist always has right-of-way. This may affect their perceptions of safety.

RQ2: Which characteristics of intersections correspond with higher or lower levels of perceived safety for cyclists?

The presence of separate cycling facilities and longer crossing distance were found to correspond with high levels of perceived safety, and the presence of crossing islands and number of traffic lanes correspond with low levels of perceived safety. The most important finding here is the role of cycling facilities across the intersection in improving safety perceptions. This finding confirms the suspicion raised in answering the first research question, and findings of many previous studies, that the presence and type of cycling infrastructure is the main determinant for safety perceptions for cyclists at intersections.

RQ3: Which groups of cyclists are the most vulnerable and how do their perceptions of cycling safety compare to those of skilled cyclists?

Primarily elderly cyclists were found to be most vulnerable, since they tend to have lower perceptions of safety in comparison to the general cycling population. Cultural background however, was shown to affect safety perceptions. Therefore, the most vulnerable cyclists in the Netherlands are those belonging to the age groups of 55-64 and 65+, as well as non-Dutch residents.

6.2 Implications for planning practice

The aim for this MSc thesis project was to identify intersection characteristics that improved perceptions of safety and could be implemented at any intersections. Improving perceptions of cycling safety is important for stimulating cycling, since it is the main determinant for deciding on cycling trips. In the urban environment, intersections form an important aspect of perceived danger for cyclists, as they are a conflict point between all different types of traffic. Therefore, by improving the perceived safety of intersections for cyclists, these intersections will offer less of a barrier in both transport mode and route choice. Removing the barrier that intersections offer would be a great improvement for the mobility of people living in the city, especially for the more vulnerable cyclists.

Unfortunately, most of the intersection treatments that were investigated in this project and that could easily be added to existing intersections (white boxes, lines, colored surfaces, give-way road markings, raised surfaces), were not found to improve perceptions of safety. However, the finding that cycling infrastructure continued across intersections does improve safety perceptions is also relevant for planning practitioners. This measure cannot be implemented everywhere, but there are certainly intersections that could be improved. Bicycle infrastructure can only continue across an intersection if the road on which it is located has right of way. If it does not, the bicycle infrastructure will be interrupted, making it a type 3c intersection. Therefore type 3c intersections cannot be changed into type 3b intersections. Type 3a and type 2a intersections however can be made into type 3b and 2b intersections respectively. This will however require a large scale change in the entire road. Therefore this finding is most relevant when considering the construction of new roads.

A further implication of this MSc thesis' findings relates to the groups that have been identified as vulnerable cyclists. Infrastructure is a public good and should therefore provide mobility to all members of society. Therefore, planning practitioners should consider the suitability of new infrastructure investments to the most vulnerable groups of potential users. This MSc thesis project has taken a first step by identifying what types of cyclists belong to such vulnerable groups.

6.3 Limitations of the research

The methodology of the MSc thesis project is associated with a number of limitations that should be addressed. First, relating to the online survey. The fact that the survey was conducted online, while having many benefits, has also excluded some people from participating. Mostly elderly users have a harder time accessing and filling in the online survey. This was reflected in the composition of respondents, with 19.7% of respondents above 65 years, where the hope was to get 50% of responses from this group. Secondly, the sampling in this project was subject to selection bias. This is due to the fact that sampling was conducted via a variety of methods, including through personal networks, online fora, bicyclist association newsletters and networks within the university. As a result the sample is not random and therefore, it is not fully representative of the population. For example, the sample included 64% males, whereas the population of Groningen is 49% male (CBS, n.d.). In terms of age the sample was more representative, with the 19-34 group being represented by 36,6% of the sample, where this is 34% in the municipality of Groningen (OIS, n.d.). Furthermore, the response rate to the survey could not be calculated as a result of these sampling methods. Third, the representation of intersections in the online survey comes with some issues. Regarding the use of Google Street View images, differing levels of traffic volumes are displayed on the screenshots. The traffic that is displayed on these images will likely have influenced perceptions of safety. For example when a respondent is faced with an image that includes many cars, they might indicate a lower level of perceived safety than if these cars were not present in the image.

A second set of limitations regards to the exclusion of certain factors from the study. Traffic volume and curb radius were not included in this MSc thesis project as potential factors affecting safety perceptions. Data on such factors would have to be collected first hand, offering too great a challenge for the time scope of this project. Mekuria et al., (2012) criticize the LOS and BCI for including such factors in their modeling of perceived safety, based on the same argumentation. Similarly, measurements regarding curb lane widths, crossing distances and bicycle lane widths also provided a challenge. This data was collected based on inferences using Google Maps.

6.4 Future research

This MSc thesis project has revealed multiple possibilities for continuations of research into safety perceptions for cyclists. Some of these have already been briefly touched upon, for example regarding the inclusion of intersections with specific characteristics in the sample. To further examine the roles of individual intersection characteristics on perceptions of safety, studies should be tailored to investigating one or a limited few characteristics. In the sample of the current thesis project, some characteristics were only represented in 6 or 7 cases. By limiting the research to a smaller set of characteristics the sample of intersections can cover more cases where these characteristics are found. Comparing within a sample of for example 30 intersections with colored intersections to 30 intersections without may provide more interesting results.

Another avenue for future research could include before-after studies when certain intersection characteristics are changed or added. This type of methodology could highlight the difference that is made by changing a single characteristic. An interesting example of this type of research is provided by Jensen (2008). This before-after study investigates the role of blue colored crossing surfaces on intersections. The strength of such an approach is that all other conditions remain mostly equal.

A third suggestion for future research is related to the vulnerability of elderly cyclists. Future research should investigate if there are any differences between what factors influence perceptions of safety between elderly cyclists and non-vulnerable cyclists. The previous chapter has discussed the importance of taking into account the perceptions of safety for elderly, vulnerable cyclists in particular. The present thesis project has not been able to investigate elderly cyclists in depth, as a result of the methodology including an online survey, limiting the potential for collecting responses among the elderly population.

7 Reflection

Overall this MSc thesis project has largely been successful in attaining its goals. The first stage was selecting and fine tuning a topic. Here it was hard to gain insight into what previous research in the field of traffic safety perceptions looked like. Therefore, it took a long time to define an exact research question and methodology. The methodology that was to be applied changed several times after gaining new insights from previous studies. Another key challenge was related to collecting responses on the online survey. The survey needed at least 250 responses in order to get enough responses per intersection. Finally, after approaching many cyclist- and traffic safety organizations and unions, some were willing to provide assistance in spreading the survey. Time management has also provided some difficulties, towards the end of the project's runtime. It became apparent that the slow progress in the first phases of the project had been too little. A timetable was constructed for the research proposal in this first phase, however it was not followed very successfully. A final challenge was related to the scope of the project. The choice was made to investigate 100 intersections with relation to a wide range of characteristics and including all kinds of images and schematics in the online survey. This broad approach provided for a very time consuming process of both gathering data and designing visuals. This point also relates to the time management, since the planning had not accounted for some of such time consuming tasks. In the end the project was finished on time however, so none of these problems proved too much. In a next research project I would be more detailed in planning the research process during the first phase. This will however always prove difficult, since new insights will always open up new avenues within the project. Research is a cyclical process, but when limited to time constraints it is important to also plan consecutive phases of this process.

With regards to the outcomes of this MSc thesis project, the outcomes do appear convincing. Many of the findings are in line with expectations based on previous research. Furthermore, the methodology that was applied was very much similar to such previous studies. This MSc thesis project really feels as if it has been able to contribute to the body of scientific knowledge on perceptions of traffic safety for cyclists, in the Netherlands particularly.

8 References

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Datasets

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Provider: Rijkswaterstaat
Website:
https://www.rijkswaterstaat.nl/apps/geoservices/geodata/dmc/bron/Documentatie/Handleiding%20product%20Bestand%20geRegistreerde%20Ongevallen%20Nederland.docx
Format: XLSX
Legal aspect: Access to the data and use of the data are free and without restrictions for users and companies.

Title: NWB (Nationaal wegenbestand)
Provider: Rijkswaterstaat
Website:
https://www.rijkswaterstaat.nl/zakelijk/zakendoen-met-rijkswaterstaat/werkwijzen/werkwijze-in-gww/data-eisen-rijkswaterstaatcontracten/nationaal-wegenbestand.aspx
Format: XLSX
Legal aspect: Access to the data and use of the data are free and without restrictions for users and companies.

9 Appendices

The appendices will be attached in a separate document. They include:

1 List of selected intersections
2 Dataset of intersection characteristics
3 Google Street view images of intersections
4 Top-down illustrations of intersections
5 Surveys (English and Dutch)
6 Statistical test outcomes from SPSS
7 GIS maps and analyses

Appendix 1: Selected intersections

Case n	Type	Coordinates	street 1	street 2
1	type 3c	53.22612038796681, 6.561178231353248	Nieuwe Ebbingestraat	Boteringesingel
2	type 3c	53.22668264692381, 6.560804640940486	Nieuwe Ebbingestraat	Korreweg
3	type 3b	53.22614736244968, 6.56178559734964	Boteringesingel	Boterdiep
4	type 3c	53.22696864033758, 6.561517231816853	Korreweg	Boterdiep
5	type 3c	53.22804738183369, 6.560141713414687	Bedumerweg	Noorderstationstraat
6	type 2a	53.22508041487245, 6.562092253147296	Violenstraat	Nieuwe Ebbingestraat
7	type 3b	53.234171781372496, 6.5767222750076755	Korreweg	Oosterhamriklaan
8	type 2b	53.23296062385483, 6.574533556175973	Korreweg	Molukkenstraat
9	type 2b	53.22532468603674, 6.562711951927257	Boterdiep	Brouwerstraat
10	type 3b	53.21666798274905, 6.584379605689484	Sontweg	Sontplein
11	type 3a	53.214655196472386, 6.562770348098603	Gedempte Zuiderdiep	Stationstraat
12	type 1	53.21902459724767, 6.567073304132326	Grote markt	Oude Ebbinge
13	type 2a	53.22114345145781, 6.562933617298006	Oude Boteringestraat	Lopendediep
14	type 3b	53.21812870185624, 6.577188017316888	Damsterdiep	Oostersingel
15	type 2a	53.22101878237938, 6.5746844357658425	Nieuwe Sint Janstraat	Oostersingel
16	type 1	53.22266639519176, 6.555713190862503	Grote Kruisstraat	Noorderbinnensingel
17	type 2b	53.208599768882635, 6.5724236782277385	Hereweg	Vechtstraat
18	type 3b	53.21036423947512, 6.5958238369490045	Herningsweg	Bornholmstraat
19	type 2b	53.19730989738073, 6.568169350163641	Van Lenneplaan	Van Iddekingeweg
20	type 2b	53.19273393261112, 6.562134338873087	Laan Corpus Den Hoorn	Hoornsedijk
21	type 2b	53.22090020954537, 6.540195779436708	Friesestraatweg	Donghornsterpad
22	type 2a	53.221098791583785, 6.528786216337939	Arduinlaan	Diamantlaan
23	type 3c	53.21314904255611, 6.539976808698344	Atoomweg	Hoendiep

24	type 3b	53.18199901686136, 6.591902325834283	Rijksstraatweg	Dilgtweg
25	type 3c	53.2328128205713, 6.553091401488049	Kastanjelaan	Eikenlaan
26	type 3b	53.23473609793546, 6.555833249618869	Misspellaan	Lepenlaan
27	type 2b	53.21416310407199, 6.546520336703174	Hoendiep	Hoendiepsbrug
28	type 2a	53.22062399018979, 6.560983892959311	Lopendediep	Kijk in het jatstraat
29	type 2a	53.2214613488616, 6.562601034119937	Nieuwe Boteringestraat	Splisluizen
30	type 2a	53.222849153314485, 6.56439353461237	Nieuwe Ebbingestraat	Wipstraat
31	type 2a	53.22350300404804, 6.563695984305264	Nieuwe Ebbingestraat	Nieuwe Kerkhof
32	type 2a	53.219192904162874, 6.567949171154761	Grote Markt	Kreupelstraat
33	type 3a	53.2256758238604, 6.557523498927725	Boteringestraat	Moesstraat
34	type 2a	53.223314637948526, 6.560372411168856	Nieuwe Kerkhof	Nieuwe Boteringestraat
35	type 1	53.22282028297917, 6.559094273002589	Grote Rozenstraat	Nieuwe Kijk in Het Jatstraat
36	type 1	53.215966348434776, 6.57131765588273	Gedempte Zuiderdiep	Radermarkt
37	type 2b	53.21686129410508, 6.573806984071153	Steenstilstraat	Schuitendiep
38	type 1	53.21649064106354, 6.57426678760598	Kostersgang	Windschoterkade
39	type 3c	53.21460582210496, 6.577561392413554	Griffeweg	Meeuwerderweg
40	type 1	53.20876094895877, 6.567570226299223	Parkweg	Achterweg
41	type 2a	53.2175142321927, 6.551982292183177	Kraneweg	Taco Mesdagstraat
42	type 2a	53.21685665405432, 6.549135739694531	Kraneweg	Sint Lucasstraat
43	type 1	53.23395617382402, 6.548464622960061	Elzenlaan	Acacialaan
44	type 1	53.236541520322774, 6.550650481448375	Esdoornlaan	Maluslaan
45	type 1	53.23313545448, 6.536414395802556	Marsstraat	Neptunusstraat
46	type 1	53.231296111029685, 6.539231325030758	Venuslaan	Plutolaan
47	type 2a	53.2297023662919, 6.546067235876124	Pleiadelaan	Dierenriemstraat
48	type 3a	53.22948139431988, 6.592695102999224	Akeleiweg	Pop Dijkemaweg

49	type 2a	53.22892539411077, 6.5932814596543325	Stadsweg	Pop Dijkemaweg
50	type 3b	53.227337588959394, 6.591050227465055	Oostersluisweg	Florakade
51	type 1	53.22731690771526, 6.590344685149085	Florakade	Crocusstraat
52	type 2a	53.22279821829452, 6.5834861578917065	Zaagmuldersweg	Linnaeusplein
53	type 2a	53.224407242722265, 6.581753378192861	Irislaan	Zaagmuldersweg
54	type 2a	53.22916459778222, 6.5758391136258005	Zaagmuldersweg	Oosterhamrikkade
55	type 2a	53.228486112565626, 6.576509784907102	Vinkenstraat	Zaagmuldersweg
56	type 1	53.21358395768643, 6.565636285122236	Coehoornsingel	Ubbo Emmiusstraat
57	type 2a	53.21498845763411, 6.572259379515498	Herebinnensingel	Radermarkt
58	type 1	53.215446141873706, 6.567438845376892	Nieuwstad	Pelsterstraat
59	type 1	53.21680566224589, 6.5624329517237925	kerkhof	Akerkstraat
60	type 1	53.219390892248896, 6.558409989282229	Hoekstraat	Gasthuisstraat
61	type 3b	53.21631646972125, 6.530453485211423	Protonstraat	Diamantlaan
62	type 3c	53.22772463425704, 6.5141527711751515	Leegeweg	De Held
63	type 1	53.22936276058591, 6.524049408797844	Topaasstraat	Edelsteenlaan
64	type 3a	53.22302297875999, 6.6096705713694135	Sint Peterburgweg	Odenseweg
65	type 3c	53.21544397999525, 6.59376689394064	Bornholmstraat	Kotkastraat
66	type 2b	53.213836443879025, 6.597469400239376	Osloweg	Helsinkistraat
67	type 2b	53.24307858034557, 6.589113618582969	Emingaheerd	Framaheerd
68	type 3b	53.187625755739155, 6.586149631369319	Esserweg	Rijksstraatweg
69	type 2b	53.18539411072473, 6.600573168174114	Dilgtweg	Kerklaan
70	type 2b	53.19483111245239, 6.594426727253552	Kooiweg	Helperzoom
71	type 2b	53.20471484710378, 6.583743854738962	Helperzoom	Haydnlaan
72	type 2b	53.19790173106056, 6.560279630328727	Overwinningsplein	Henri Dunantlaan
73	type 2b	53.19099744451834, 6.5572999847039295	SOJ Palmelaan	JM Den Uylstraat

74	type 2b	53.19288014473538, 6.565665260106022	Van Ketwich Verstuurlaan	Nicolaas Beetstraat
75	type 3c	53.205606623038015, 6.6129420873275375	Rigaweg	Bornholmstraat
76	type 3b	53.22566581087374, 6.593186262661754	Damsterdiep	Oostersluisweg
77	type 2b	53.22965582647681, 6.5568181062266095	Noorderstationstraat	Parallelweg
78	type 2b	53.231091656998586, 6.554031021069837	Kastanjelaan	Magnoliastraat
79	type 3b	53.23343388092832, 6.55626162543061	Eikenlaan	Lepenlaan
80	type 3b	53.220605797650165, 6.583485051392997	Damsterdiep	Zaagmuldersweg
81	type 2b	53.20796878795759, 6.557687796277108	Paterswoldseweg	Verzetstrijderslaan
82	type 2b	53.21135164222246, 6.556202319185267	Paterswoldseweg	Kleine Badstraat
83	type 3b	53.214758044753516, 6.549826517379649	Hoendiep	Friesestraatweg
84	type 3c	53.214693032232816, 6.552201142481964	Hoendiepskade	Eendrachtskade
85	type 2b	53.20450804025232, 6.574706256917567	Hereweg	Papiermolenlaan
86	type 3a	53.19519568365469, 6.568384890018684	Bilderdijklaan	Van Lenneplaan
87	type 2a	53.207417385094374, 6.561157451436711	Hoornsediep	Parkweg
88	type 2b	53.205700593965474, 6.563368592020112	Rivierenhof	Hoornsediep
89	type 3a	53.21972987097118, 6.567635544725817	Kreupelstraat	Kwinkenplein
90	type 2a	53.220473981354566, 6.567704394069066	Kreupelstraat	Jacobijnstraat
91	type 1	53.21860909062405, 6.565306305575981	Zwanestraat	Oude Boteringestraat
92	type 1	53.220520230827454, 6.545927812846776	Nassauplein	Amalia van Solmsstraat
93	type 2b	53.221773698096065, 6.547299156220945	Prinsessenweg	Graaf Adolfstraat
94	type 2b	53.21980476766558, 6.5522757376389675	Koninginnelaan	Wilhelminakade
95	type 2a	53.21898054911318, 6.5559643763357265	Westersingel	Reitdiepskade
96	type 3b	53.1595007057167, 6.614315308129289	Rijksstraatweg	Docter EH Ebelsweg
97	type 3a	53.16820407503488, 6.614042746979422	Jachtlaan	Onnerweg
98	type 3b	53.23435582070136, 6.613500202556218	Vaargeul	Lichtboei

99	type 3c	53.217497552094926, 6.573223713931186	Schuitendiep	Gedempte Kattendiep
100	type 1	53.21141717698289, 6.574244955924085	Sophiastraat	Mauritsstraat

Appendix 2: Intersection Characteristics part 1

Case n	Type	Speed limit	Lanes	1/2-way	Bike lane	Bike path	Continued bikelane	Legs	Bikelane width	Curblane width	Crossing distance
1	type 3c	50	2	1	No	Yes	No	4	1,6	5,5	5,6
2	type 3c	50	2	1	No	Yes	No	4	1,9	4,9	6,5
3	type 3b	50	2	2	Yes	No	Yes	3	2	4,11	15
4	type 3c	50	2	1	No	Yes	No	4	1,8	3,2	9,4
5	type 3c	50	2	1	Yes	No	No	4	1,9	3,2	7,3
6	type 2a	50	2	2	No	No	No	4	0	2,8	6,5
7	type 3b	50	2	2	No	Yes	Yes	4	2,11	4,2	8,5
8	type 2b	50	2	2	No	Yes	Yes	4	2	3	9
9	type 2b	50	2	2	Yes	No	Yes	3	1,8	3,1	5,8
10	type 3b	50	4	2	No	Yes	Yes	4	1,8	3,2	18,3
11	type 3a	50	2	1	No	No	No	3	0	4,1	11
12	type 1	30	2	2	No	No	No	3	0	4	6,2
13	type 2a	50	2	1	No	No	No	4	0	4,3	7,3
14	type 3b	50	2	2	Yes	No	Yes	5	2,1	4	13,5
15	type 2a	50	2	2	No	No	No	3	0	4,3	6
16	type 1	30	2	2	No	No	No	4	0	2,9	12,3
17	type 2b	50	2	2	No	Yes	Yes	3	2,4	3,3	6,5
18	type 3b	50	2	2	No	No	Yes	3	1,8	3,3	10
19	type 2b	50	2	2	Yes	No	Yes	4	1,7	2,9	13
20	type 2b	50	2	2	No	Yes	No	4	1,3	0	17,5
21	type 2b	30	2	2	No	Yes	No	4	2,1	0	7,1
22	type 2a	50	2	2	Yes	No	No	4	1,5	5,7	16,5
23	type 3c	50	2	2	No	Yes	No	4	2,4	2,8	22,1
24	type 3b	50	2	2	No	Yes	Yes	3	3	3,4	14,4
25	type 3c	50	2	2	Yes	No	No	3	1,5	3,2	9,9
26	type 3b	50	2	2	Yes	No	Yes	4	1,6	3	14,3
27	type 2b	50	2	2	No	Yes	Yes	4	2,6	0	9,3
28	type 2a	50	2	1	No	No	No	4	0	4,8	6,9

Case n	Type	Speed limit	Lanes	1/2-way	Bike lane	Bike path	Continued bikelane	Legs	Bikelane width	Curblane width	Crossing distance
29	type 2a	50	1	1	No	No	No	4	0	3,5	5,5
30	type 2a	50	2	1	No	No	No	4	0	3,2	6,8
31	type 2a	50	2	1	No	No	No	4	0	4,5	6
32	type 2a	30	2	2	No	No	No	4	0	3,2	11,2
33	type 3a	50	2	2	No	No	No	4	0	3,7	13,3
34	type 2a	50	2	2	No	No	No	4	0	3,1	11
35	type 1	30	1	1	No	No	No	4	0	4,2	4,2
36	type 1	30	1	1	No	No	No	4	0	4,7	7
37	type 2b	50	2	1	Yes	No	No	4	0	3,4	13,2
38	type 1	30	1	1	No	No	No	3	0	3,5	4,7
39	type 3c	50	2	2	Yes	No	No	4	1,6	3,2	12
40	type 1	50	2	1	No	No	No	4	0	3	22,2
41	type 2a	50	2	2	No	No	No	4	0	2,8	6
42	type 2a	50	2	2	No	No	No	3	0	3,2	6
43	type 1	50	2	2	No	No	No	4	0	3,6	9,4
44	type 1	50	2	2	No	No	No	4	0	3,2	7,2
45	type 1	50	2	2	No	No	No	4	0	2	7,5
46	type 1	50	2	2	No	No	No	4	0	2,9	7,8
47	type 2a	50	2	2	No	No	No	3	0	2,5	8,8
48	type 3a	50	2	2	No	No	No	3	0	4,2	7,8
49	type 2a	50	2	2	No	No	No	3	0	2,8	7,8
50	type 3b	50	2	2	Yes	No	Yes	4	1,8	4,3	13,2
51	type 1	50	2	2	No	No	No	3	0	3,8	9,2
52	type 2a	50	2	2	No	No	No	3	0	2,8	7,5
53	type 2a	50	2	2	No	No	No	3	0	3,2	6
54	type 2a	30	2	2	No	No	No	3	0	3,6	7,9
55	type 2a	30	2	2	No	No	No	4	0	2,9	7,5
56	type 1	30	1	1	No	No	No	4	0	3	5,1
57	type 2a	50	2	2	No	No	No	4	0	3,1	6,8
58	type 1	50	1	1	No	No	No	3	0	2,6	6
59	type 1	30	2	2	No	No	No	4	0	2,8	7,2

Case n	Type	Speed limit	Lanes	1/2-way	Bike lane	Bike path	Continued bikelane	Legs	Bikelane width	Curblane width	Crossing distance
60	type 1	30	1	1	No	No	No	4	0	2,7	3,8
61	type 3b	50	2	2	No	Yes	Yes	3	2,1	3,8	9,5
62	type 3c	50	2	2	No	Yes	No	4	1,8	3	6,5
63	type 1	30	2	2	No	No	No	3	0	3	8,5
64	type 3a	50	4	2	No	No	No	4	0	3,6	13,8
65	type 3c	50	2	2	Yes	No	No	4	1,7	3,2	16
66	type 2b	50	2	2	Yes	No	Yes	3	1,4	3,3	8,8
67	type 2b	30	2	2	Yes	No	Yes	4	1,4	3	9,2
68	type 3b	50	2	2	Yes	No	Yes	4	2,4	3,8	15,1
69	type 2b	30	2	2	Yes	No	Yes	3	1,6	3	10
70	type 2b	50	2	2	Yes	No	Yes	4	1,9	2,9	5,8
71	type 2b	50	2	2	Yes	No	Yes	3	1,7	3	5,7
72	type 2b	50	2	2	Yes	No	Yes	3	1,6	2,8	10,6
73	type 2b	50	2	2	Yes	No	Yes	4	2	3,2	5,2
74	type 2b	50	2	2	Yes	No	Yes	3	2,2	4,4	7,6
75	type 3c	50	2	2	Yes	No	No	4	2,4	4,4	26
76	type 3b	50	2	2	Yes	No	Yes	3	1,6	3,3	14,6
77	type 2b	50	2	2	Yes	No	Yes	4	2,8	3,5	8,5
78	type 2b	50	2	2	Yes	No	Yes	4	2,4	5,3	8,5
79	type 3b	50	2	2	Yes	No	Yes	3	2,2	4,3	18
80	type 3b	50	2	2	Yes	No	Yes	3	1,8	4	12
81	type 2b	50	2	2	Yes	No	Yes	3	2,2	3	11,2
82	type 2b	50	2	1	Yes	No	Yes	3	2,8	2,9	6,2
83	type 3b	50	2	2	Yes	No	Yes	4	1,6	4,4	14
84	type 3c	50	1	1	Yes	No	No	4	2,2	3,8	14,2
85	type 2b	50	2	2	Yes	No	Yes	4	2,7	3,5	6,5
86	type 3a	50	2	2	No	No	No	3	0	2,8	11,9
87	type 2a	50	2	2	No	No	No	4	0	2	8,6
88	type 2b	50	2	2	Yes	No	Yes	3	1,4	3,4	6,3
89	type 3a	50	2	2	No	No	No	3	0	5,3	13,6
90	type 2a	50	2	2	No	No	No	4	0	3,2	9,3

Case n	Type	Speed limit	Lanes	1/2-way	Bike lane	Bike path	Continued bikelane	Legs	Bikelane width	Curblane width	Crossing distance
91	type 1	30	2	2	No	No	No	4	0	3,6	8
92	type 1	30	1	1	No	No	No	3	0	3,2	8,1
93	type 2b	50	2	2	Yes	No	Yes	4	1,9	3	4,6
94	type 2b	50	2	2	Yes	No	Yes	3	2,1	3,4	8,5
95	type 2a	50	2	2	Yes	No	No	4	0	4,4	8
96	type 3b	50	2	2	Yes	No	Yes	4	2,2	4,1	13
97	type 3a	50	2	2	No	No	No	4	0	2,6	11,6
98	type 3b	50	2	2	Yes	No	Yes	3	1,6	2,6	10,7
99	type 3c	50	2	2	Yes	No	No	3	1,6	3	21,4
100	type 1	30	2	2	No	No	No	3	0	2,3	9,8

Appendix 2: Intersection Characteristics part 2

Case n	Give-way markings	White boxes	Lines indicating cyclists	Uitrit	Raised intersection	Crossing island	Colored surface	Crosswalk	Mean perceived safety level
1	Yes	No	No	No	No	No	No	Yes	1,89
2	Yes	No	No	No	No	No	No	Yes	1,86
3	Yes	Yes	No	No	No	Yes	No	Yes	2,47
4	Yes	No	No	No	No	Yes	No	Yes	1,83
5	Yes	No	No	No	No	No	No	Yes	1,57
6	No	No	No	Yes	No	No	No	No	1,67
7	Yes	Yes	No	Yes	No	No	No	Yes	2,84
8	No	Yes	No	Yes	No	No	No	Yes	2,7
9	No	No	No	Yes	No	No	No	Yes	3,3
10	Yes	Yes	No	No	No	No	No	No	2,3
11	Yes	No	No	No	No	No	No	Yes	2,11
12	No	No	No	No	No	No	No	Yes	2,37
13	Yes	No	No	Yes	No	No	No	Yes	1,89
14	Yes	Yes	No	No	No	No	No	Yes	2,38
15	Yes	No	No	No	No	No	No	Yes	2,21
16	No	No	No	No	No	No	No	No	3,06
17	No	Yes	No	Yes	No	No	No	No	2,35
18	Yes	Yes	No	No	No	No	No	No	2,3
19	No	No	Yes	Yes	No	No	No	No	2,94
20	Yes	No	Yes	No	No	Yes	No	No	1,88
21	Yes	No	No	No	No	No	No	No	2,65
22	Yes	No	No	Yes	No	No	No	Yes	2,37
23	Yes	No	Yes	No	No	Yes	No	No	2,46
24	Yes	Yes	No	No	No	Yes	No	No	2,68
25	Yes	No	No	No	No	No	No	Yes	2,28
26	Yes	No	Yes	No	No	No	No	Yes	2,83
27	Yes	No	Yes	No	No	Yes	No	Yes	2,19
28	Yes	No	No	Yes	No	No	No	Yes	1,89

Case n	Give-way markings	White boxes	Lines indicating cyclists	Uitrit	Raised intersection	Crossing island	Colored surface	Crosswalk	Mean perceived safety level
29	Yes	No	No	Yes	No	No	No	Yes	2,38
30	No	No	No	Yes	No	No	No	No	2,14
31	Yes	No	No	Yes	No	No	No	Yes	2,18
32	Yes	No	No	No	No	No	No	Yes	2,03
33	No	No	No	No	Yes	No	Yes	No	2,5
34	No	No	No	No	Yes	No	Yes	No	2,14
35	No	No	No	No	No	No	No	No	2,89
36	Yes	No	No	No	No	No	No	Yes	2,06
37	Yes	No	No	Yes	No	No	No	Yes	2,46
38	No	No	No	No	No	No	No	No	2,28
39	Yes	No	No	No	No	No	No	Yes	2,17
40	No	No	No	No	Yes	No	Yes	No	2,61
41	No	No	No	Yes	No	No	No	Yes	2,39
42	No	No	No	Yes	No	No	No	No	2,39
43	No	No	No	Yes	No	No	No	No	2,66
44	No	No	No	No	No	No	No	No	2,55
45	No	No	No	No	Yes	No	Yes	No	2,61
46	No	No	No	Yes	No	No	No	Yes	2,72
47	No	No	No	Yes	No	No	No	Yes	2,5
48	Yes	No	No	No	No	No	No	Yes	2,56
49	Yes	No	No	No	No	No	No	No	2,37
50	Yes	Yes	No	No	No	Yes	No	Yes	2,33
51	No	No	No	No	No	No	No	No	2,33
52	Yes	No	No	No	No	No	No	Yes	2,92
53	No	No	No	Yes	No	No	No	Yes	2,44
54	Yes	No	No	No	No	No	No	Yes	2,24
55	No	No	No	No	No	No	Yes	No	2,21
56	No	No	No	Yes	No	No	No	No	2,26
57	Yes	No	No	No	No	No	No	No	2,67
58	No	No	No	Yes	No	No	No	No	2,17
59	No	No	No	Yes	No	No	No	Yes	2,25

Case n	Give-way markings	White boxes	Lines indicating cyclists	Uitrit	Raised intersection	Crossing island	Colored surface	Crosswalk	Mean perceived safety level
60	No	No	No	No	No	No	No	No	2,03
61	Yes	Yes	No	No	No	No	No	No	2,55
62	Yes	No	Yes	No	No	No	No	No	2,25
63	No	No	No	No	No	No	No	No	3,37
64	Yes	No	No	No	No	No	No	Yes	1,28
65	Yes	No	Yes	No	No	Yes	No	No	2,21
66	Yes	Yes	No	No	No	No	No	No	2,89
67	Yes	Yes	No	No	No	No	No	No	2,84
68	Yes	Yes	No	Yes	No	No	No	Yes	2,86
69	Yes	Yes	No	No	Yes	No	Yes	No	2,44
70	No	No	No	Yes	No	No	No	No	2,83
71	Yes	No	Yes	No	No	No	No	Yes	2,72
72	No	No	No	Yes	No	No	No	No	3,06
73	Yes	Yes	No	No	No	No	No	No	2,83
74	No	No	No	Yes	No	No	No	No	3,09
75	Yes	No	Yes	No	No	Yes	No	No	2,26
76	Yes	Yes	No	No	No	No	No	Yes	2,89
77	Yes	Yes	No	No	No	No	No	No	2,43
78	No	No	No	Yes	No	No	No	Yes	3
79	Yes	Yes	No	No	No	No	No	Yes	2,67
80	Yes	Yes	No	No	No	No	No	Yes	2,63
81	No	No	No	Yes	No	No	No	No	2,97
82	No	Yes	No	Yes	No	No	No	No	2,86
83	Yes	Yes	No	No	No	Yes	No	Yes	2,39
84	Yes	No	Yes	No	No	No	No	No	2,31
85	Yes	No	No	Yes	No	No	No	No	2,64
86	No	No	No	No	Yes	No	No	No	2,38
87	No	No	No	Yes	No	No	No	No	2,11
88	No	No	No	Yes	No	No	No	No	2,59
89	Yes	No	No	No	No	No	No	Yes	2,29
90	No	No	No	Yes	No	No	No	No	1,95

Case n	Give-way markings	White boxes	Lines indicating cyclists	Uitrit	Raised intersection	Crossing island	Colored surface	Crosswalk	Mean perceived safety level
91	No	No	No	Yes	No	No	No	No	2,49
92	No	No	No	No	No	No	No	No	2,71
93	Yes	No	No	Yes	No	No	No	Yes	2,84
94	No	Yes	No	No	No	No	No	Yes	2,97
95	Yes	No	No	Yes	No	No	No	No	2,53
96	Yes	Yes	No	No	No	Yes	No	No	2,37
97	No	No	No	No	Yes	No	No	No	2,25
98	Yes	No	No	No	No	No	No	No	2,6
99	Yes	No	Yes	No	No	No	No	Yes	2,03
100	No	No	No	Yes	No	No	No	No	2,83

Appendix 3: Images of selected intersections

Case 1

Case 2

Case 3

Case 4

Case 5

Case 6

Case 7

Case 8

Case 9

Case 10

Case 11

Case 12

Case 13

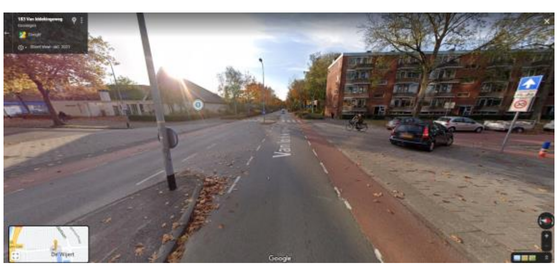
Case 14

Case 15

Case 16

Case 17

Case 18



Case 19

Case 20


Case 21


Case 22


Case 23


Case 24


Case 25


Case 26


Case 27


Case 28


Case 29


Case 30

Case 31

Case 32

Case 33

Case 34

Case 35

Case 36

Case 37

Case 38

Case 39

Case 40


Case 41


Case 42


Case 43


Case 44


Case 45


Case 46


Case 47


Case 48


Case 49


Case 50

Case 51

Case 52

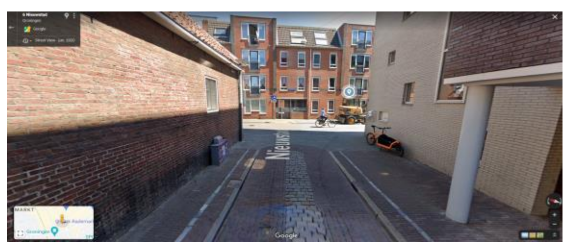
Case 53

Case 54

Case 55

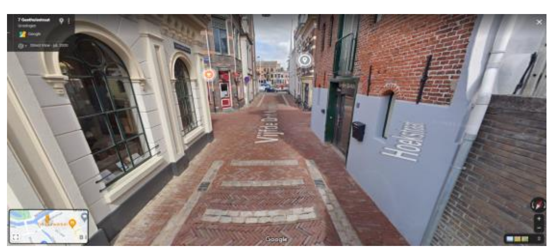
Case 56

Case 57



Case 58

Case 59



Case 60

Case 61

Case 62

Case 63

Case 64

Case 65

Case 66

Case 67

Case 68

Case 69

Case 70


Case 71


Case 72


Case 73


Case 74


Case 75


Case 76


Case 77


Case 78


Case 79


Case 80

Case 81 Case 82

Case 83 Case 84

Case 85 Case 86

Case 87 Case 88

Case 89 Case 90

Case 91

Case 92

Case 93

Case 94

Case 95

Case 96

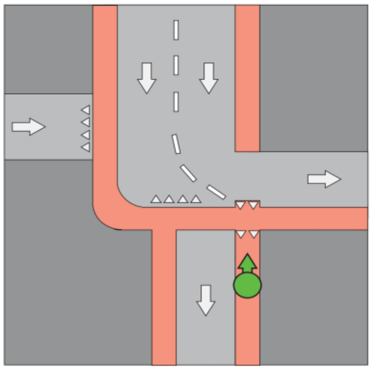
Case 97

Case 98

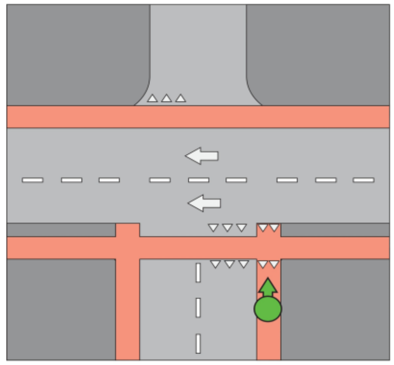
Case 99

Case 100

Appendix 4: Intersection illustrations



Case 1



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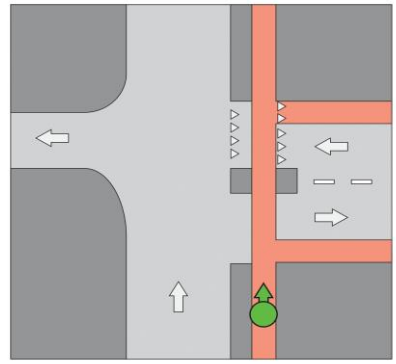
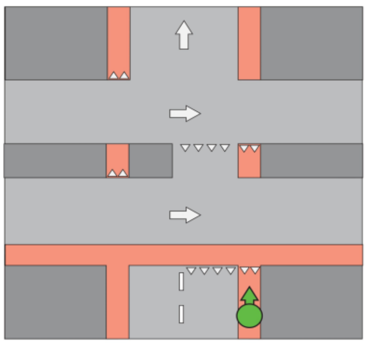
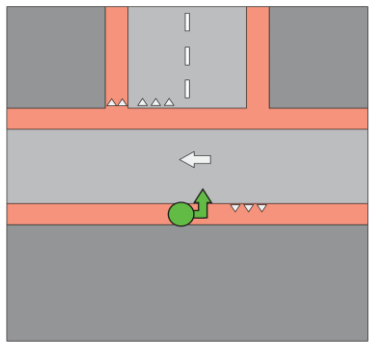


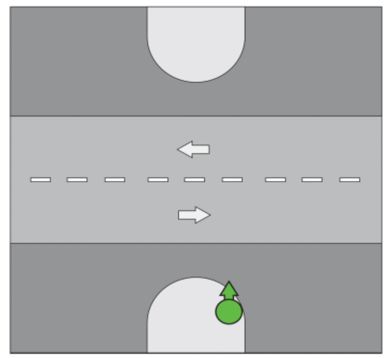
Case 3



Case 4



Case 5



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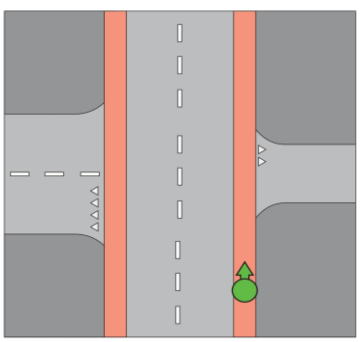
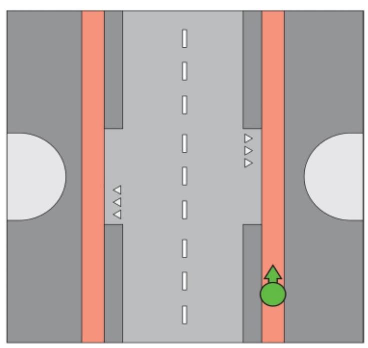
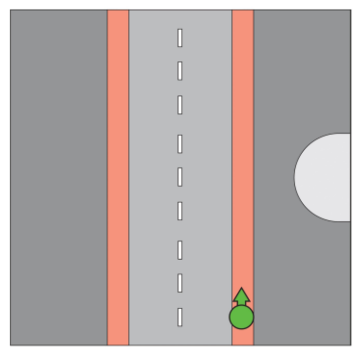


Case 7



Case 8



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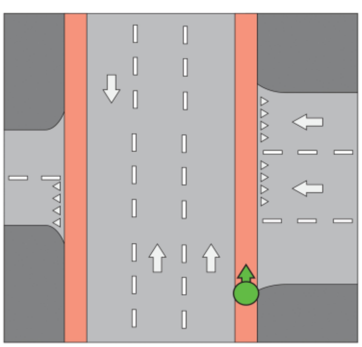

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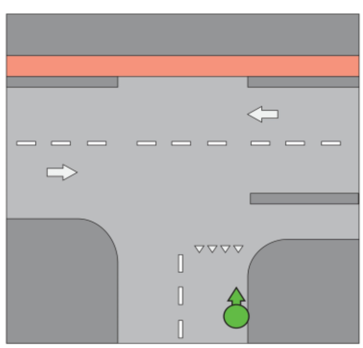

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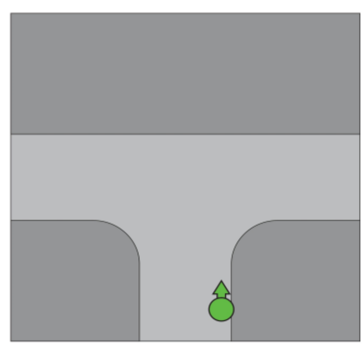

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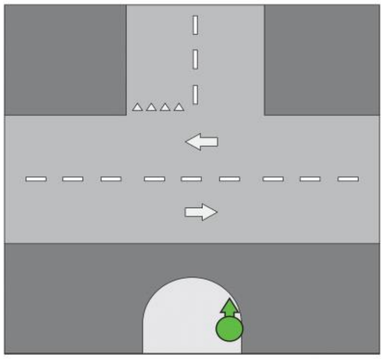

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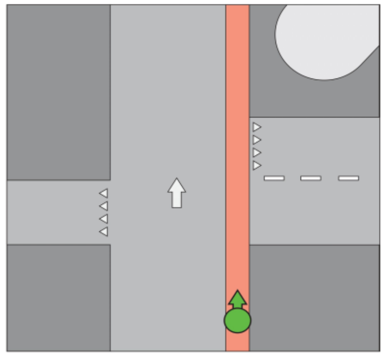

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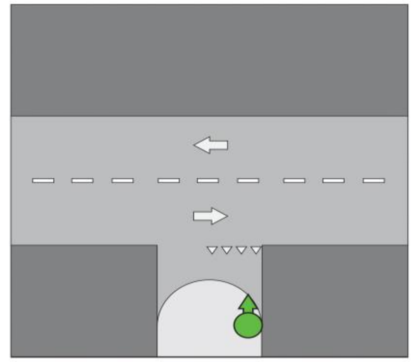

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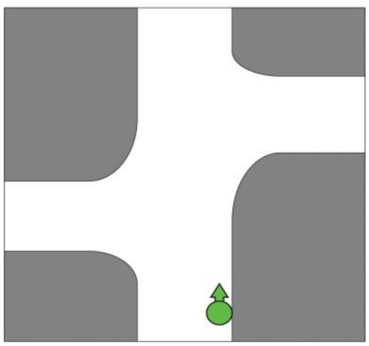

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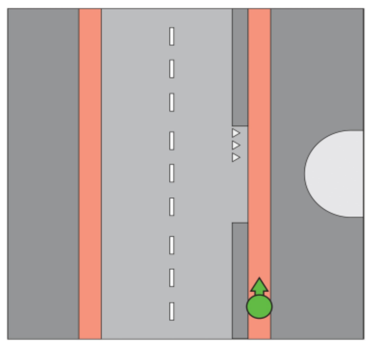

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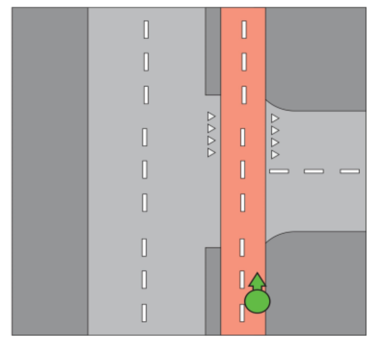

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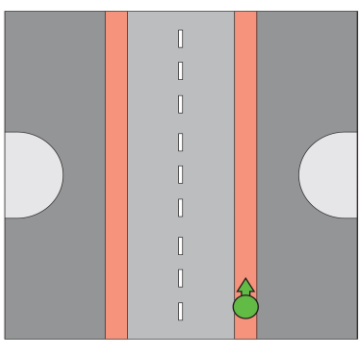

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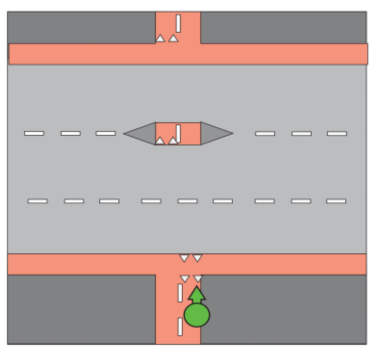

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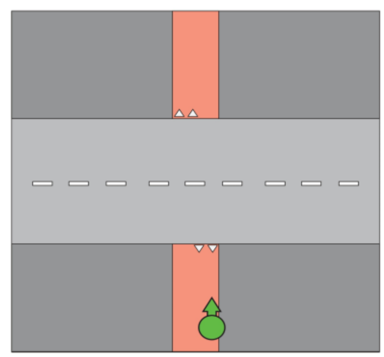

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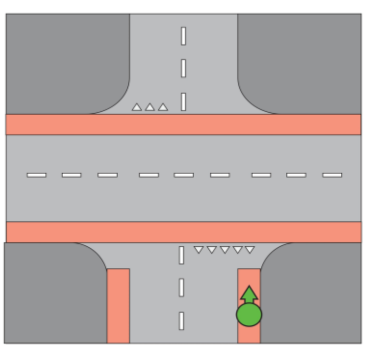

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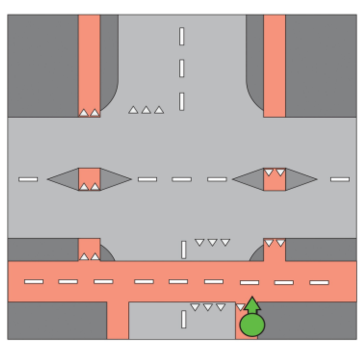

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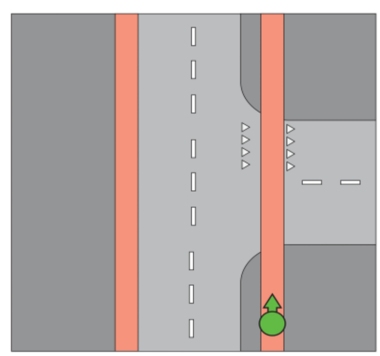

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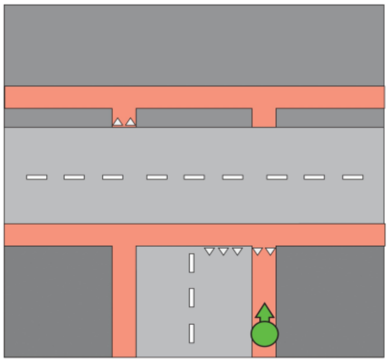
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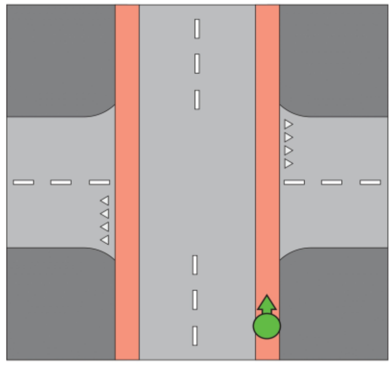
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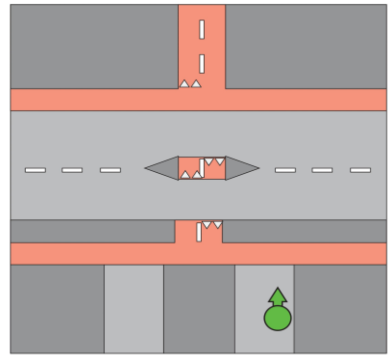
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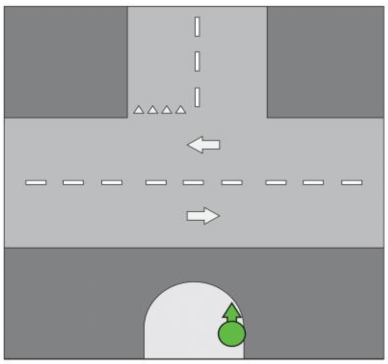
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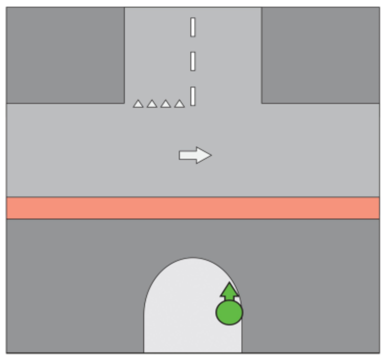
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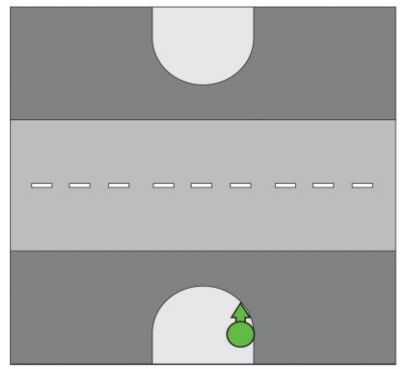
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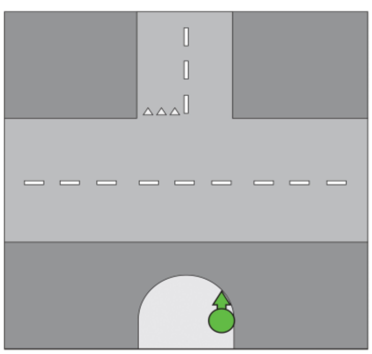
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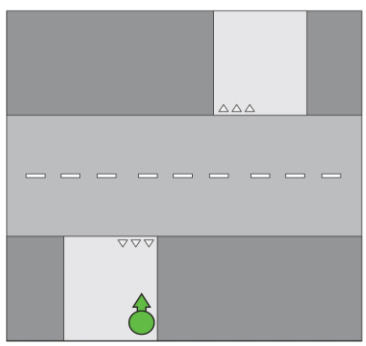
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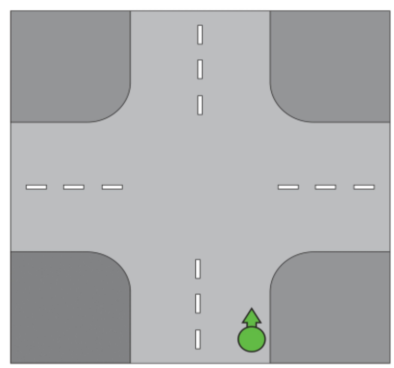
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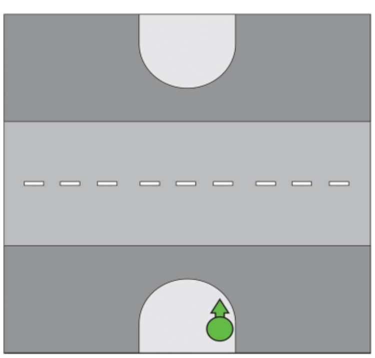
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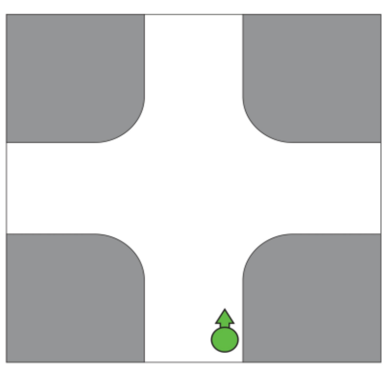
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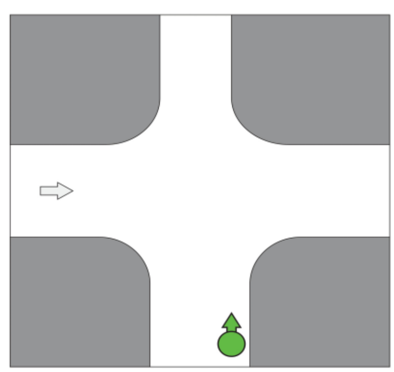
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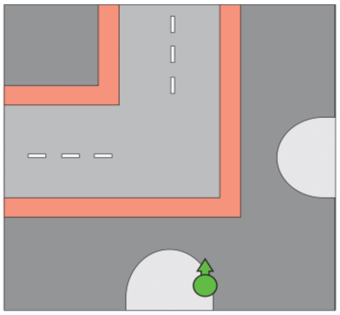

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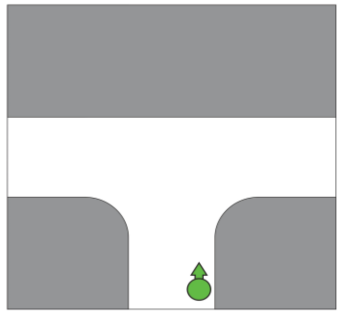

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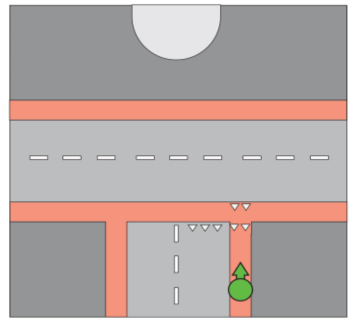

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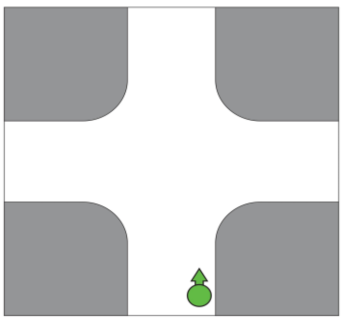

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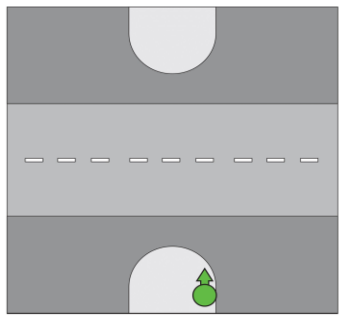

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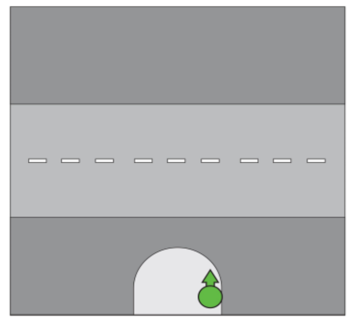

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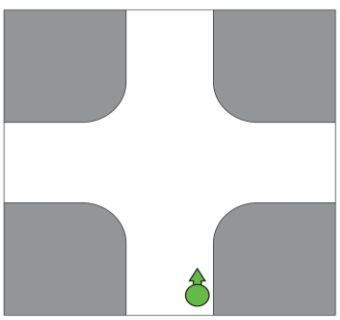

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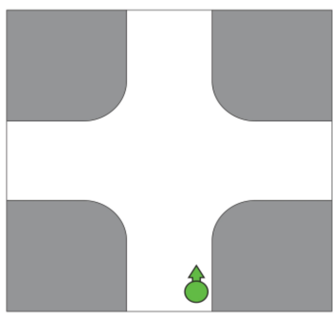

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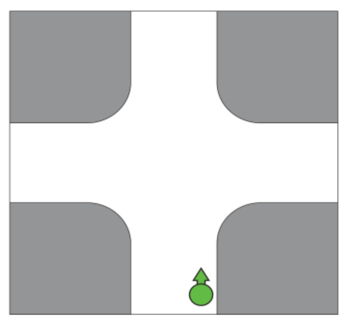

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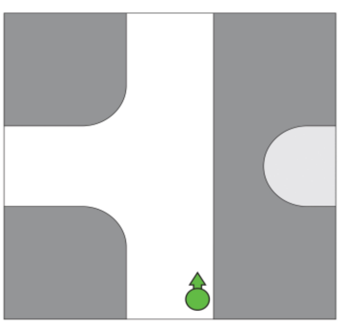

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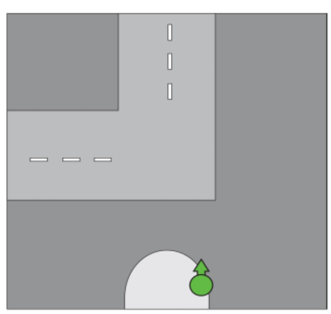

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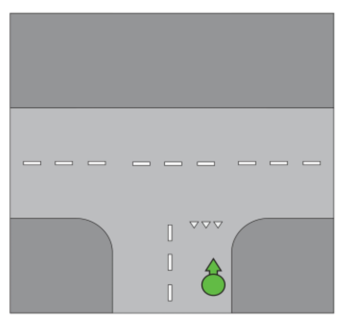

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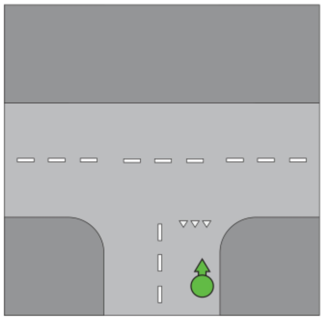

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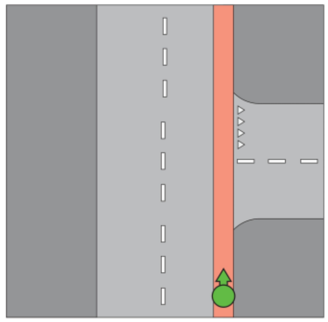

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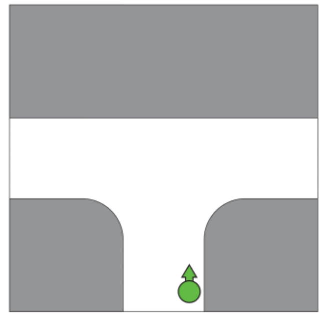

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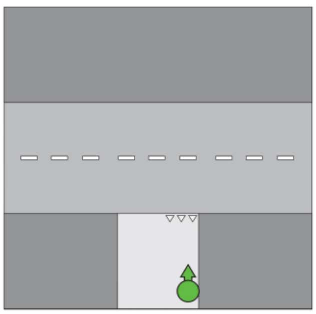

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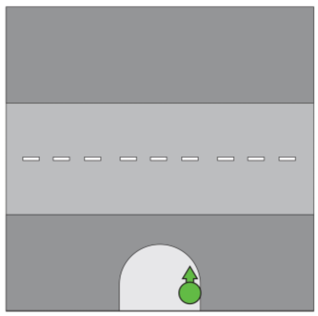

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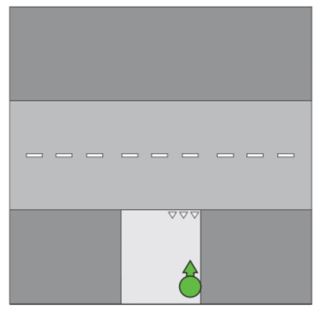

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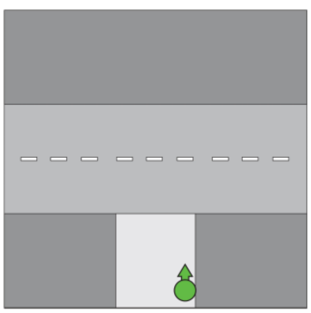

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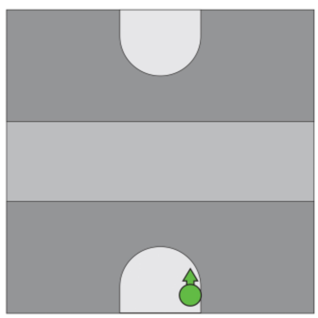

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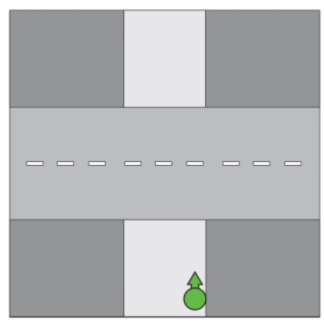

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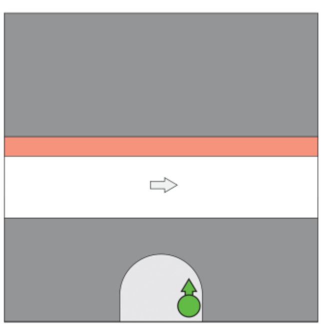

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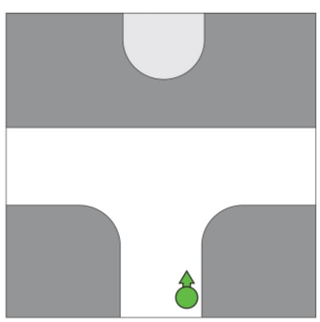

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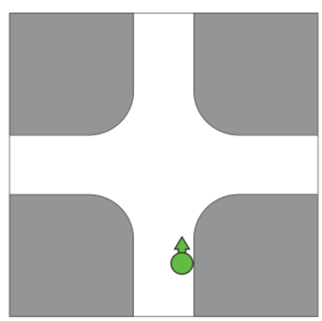

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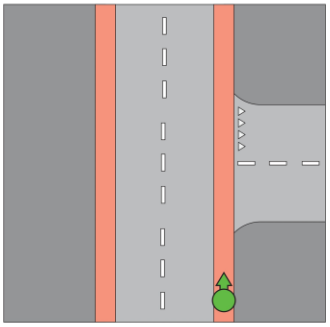
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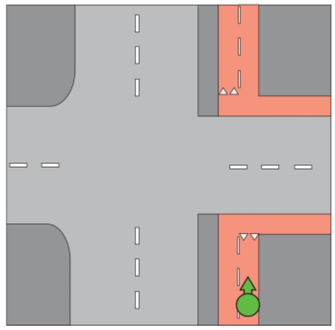
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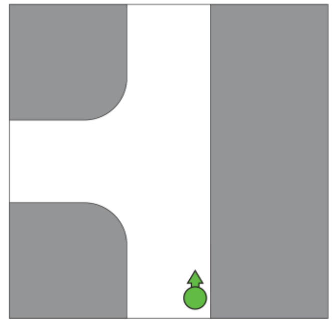
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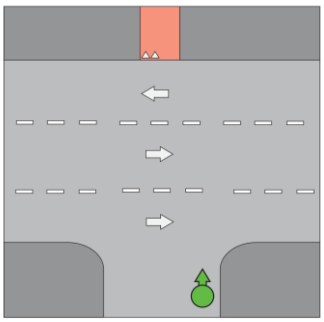
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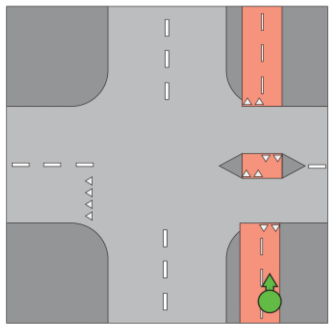
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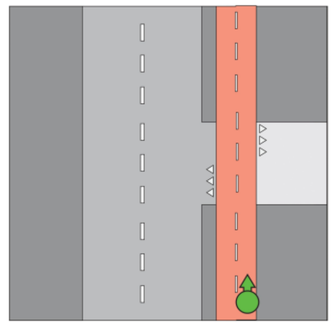
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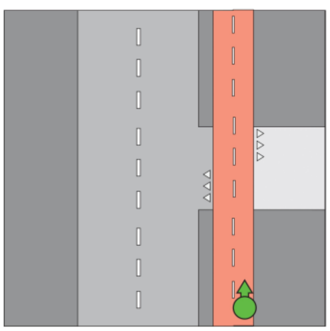
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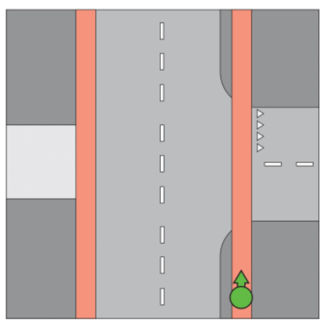
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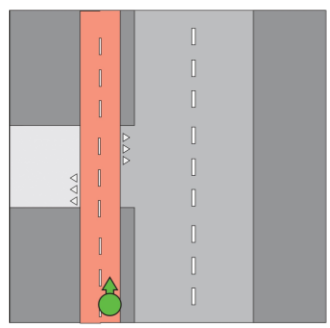
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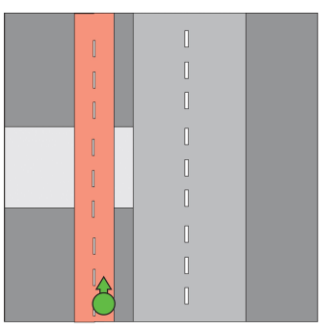
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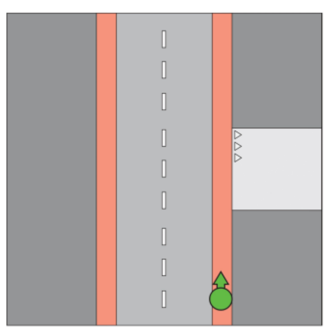
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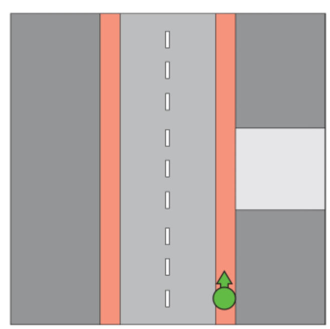
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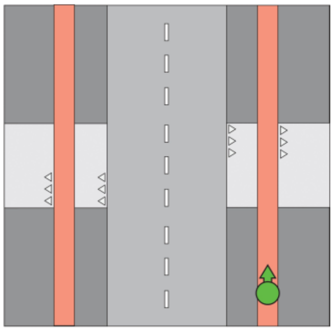

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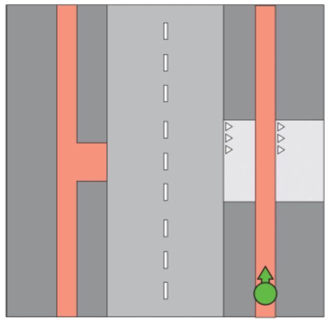

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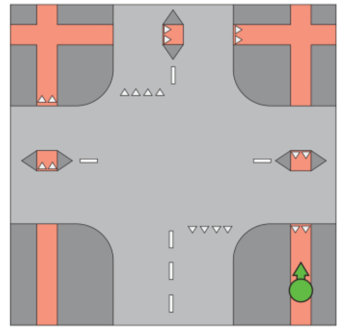

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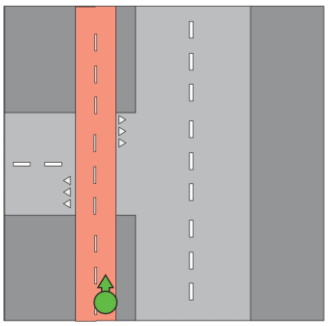

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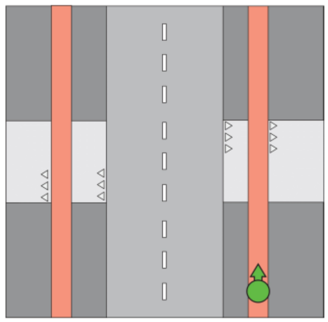

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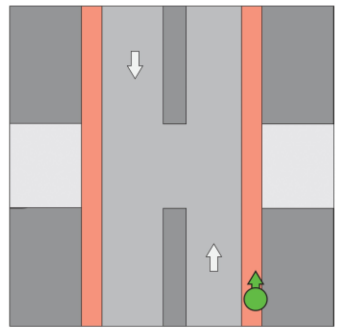

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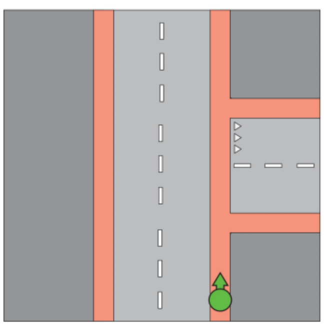

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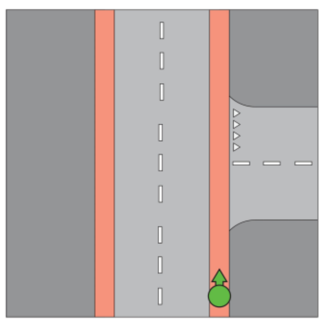

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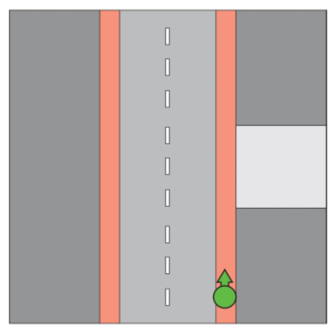

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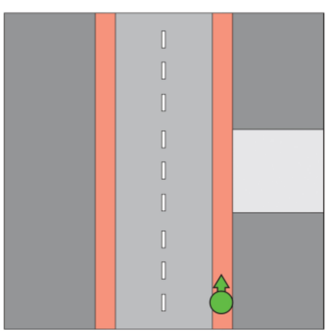
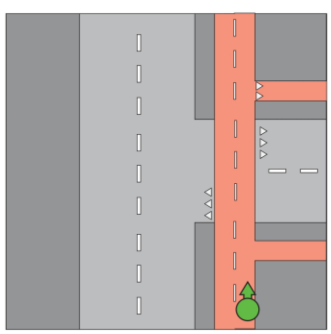
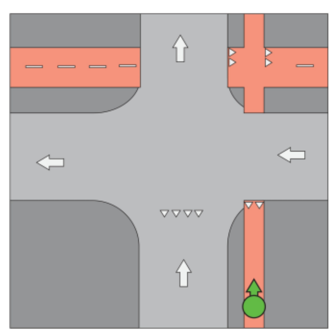


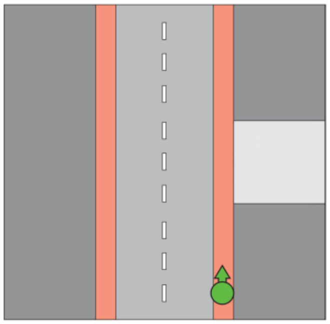
Case 82

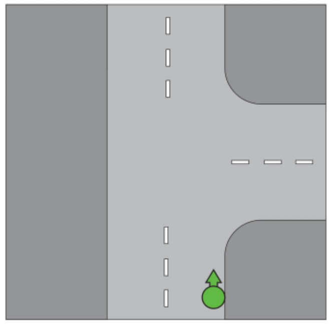


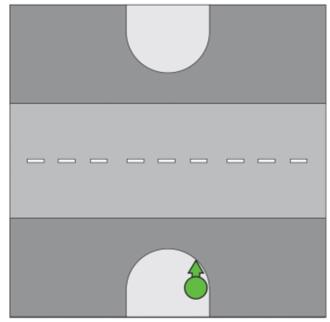
Case 83

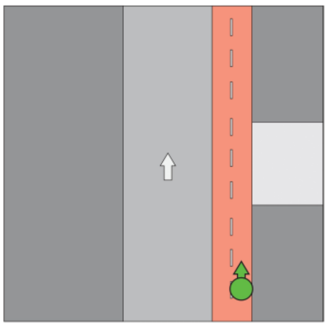


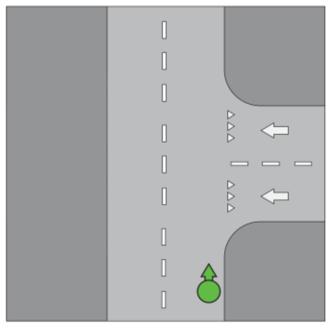
Case 84

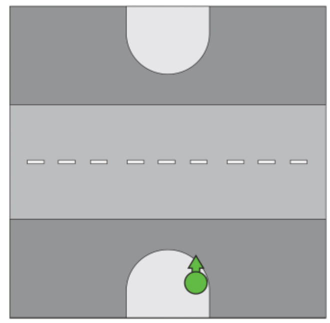

Case 85

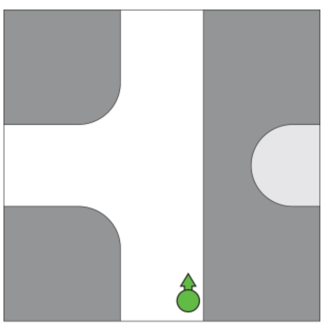

Case 86

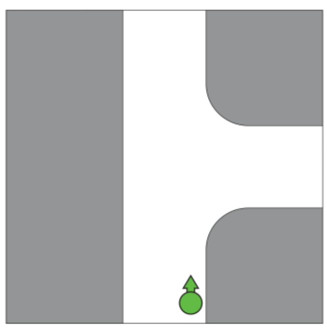

Case 87

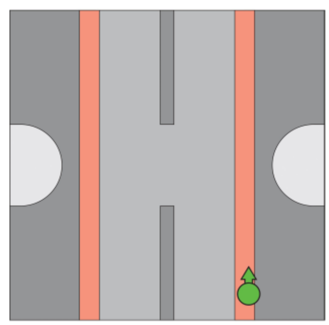

Case 88

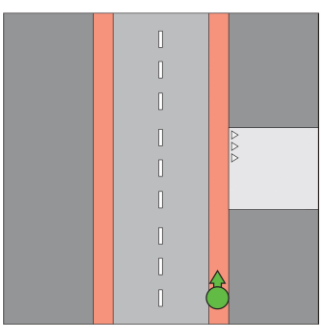

Case 89

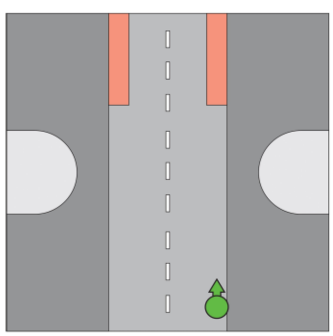

Case 90

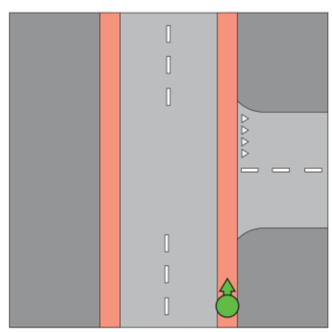

Case 91

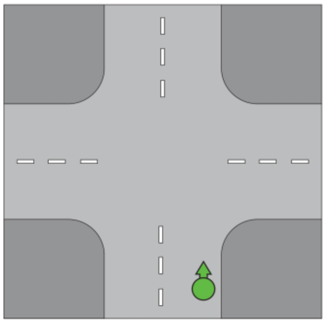

Case 92

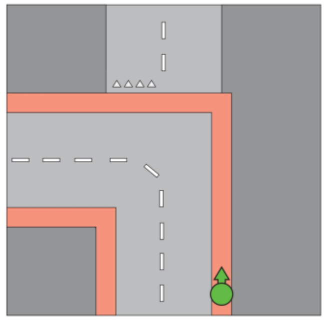

Case 93

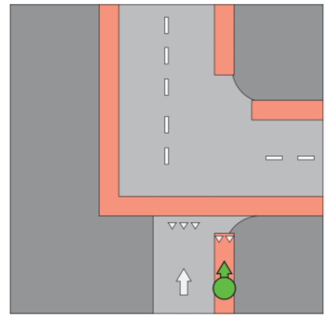

Case 94

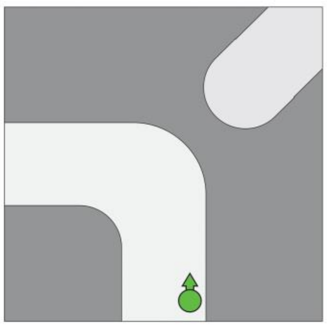

Case 95


Case 96


Case 97


Case 98


Case 99


Case 100

Appendix 5 Survey

Version A: English

Dear participant, thank you for participating in this survey.

This survey investigates perceived safety for cyclists on intersections in Groningen in order to find out where and how improvements could be made.

All data will be collected anonymously and will only be used for the purpose of this study.

The survey will take about 7-9 minutes.

Any questions can be directed to Sam van Nieuwkuijk at S.R.van.Nieuwkuijk@student.rug.nl

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The first section of the survey includes general inquiries about your background, as well as your cycling experience.

1 How old are you?

- 0-18
- 18-34
- 35-44
- 45-54
- 55-64
- 65+

2 What is your gender?

- male
- female
- other
- prefer not to answer

3 Where are you from originally?

- Netherlands
- Europe
- Outside of Europe

4 How long have you lived in the Netherlands?

- less than six months
- six months - one year
- less than two years
- less than five years
- more than five years

5 How regularly do you cycle?

at least once a year
at least once a month
1-2 times a week

3-4 times a week
5-7 times a week

6 How skilled would you say you are at cycling?
1 not skilled
2 not very skilled
3 somewhat skilled
4 skilled
5 totally skilled

7 Do you generally feel safe/comfortable while cycling?
1 very unsafe
2 quite unsafe
3 somewhat safe
4 safe
5 very safe

The second section presents you with a set of 12 intersections you could encounter riding your bike in the city of Groningen. Each scenario is represented with an image from google street view and a top-down overview of the intersection.

For each intersection you will be asked to indicate your perception of the safety of that intersection. In every scenario you start at the green arrow and cross the intersection straight ahead. In some scenarios you can't go straight ahead, here you still cross the intersection and then turn left.

Scenario X/12

<PICTURE>
View from the side you approach the intersection.

<ILLUSTRATION>
Top-down view of the intersection. The green arrow indicates your approach in this scenario.

How safe would you feel crossing the intersection in the scenario presented above
1 very unsafe
2 unsafe
3 somewhat safe
4 safe
5 very safe

You have reached the end of the survey.

Thank you again for participating.

Any questions or remarks can be directed towards S.R.van.Nieuwkuijk@student.rug.nl
----

Version B: Dutch

Beste deelnemer, bedankt voor uw deelname aan dit onderzoek.
Deze vragenlijst is onderdeel van een onderzoek naar de ervaringen van veiligheid voor fietsers op kruispunten, in de gemeente Groningen.

Alle gegevens worden anoniem verzameld en alleen gebruikt voor dit onderzoek.

Het onderzoek zal ongeveer 7-9 minuten duren.

Voor vragen kun je terecht bij Sam van Nieuwkuijk via S.R.van.Nieuwkuijk@student.rug.nl

----

Het eerste deel van de enquête bevat algemene vragen over uw achtergrond en uw ervaring als fietser.

1 Hoe oud bent u?

- 0-18
- 19-34
- 35-44
- 45-54
- 55-64
- 65+

Wat is uw geslacht?

- Mannelijk
- Vrouwelijk
- Niet-binair / derde geslacht
- Zeg ik liever niet

Waar kom je oorspronkelijk vandaan?

- Nederland
- Europa
- Buiten Europa

Hoe lang woont u al in Nederland?

- minder dan een half jaar
- minder dan een jaar
- minder dan twee jaar
- minder dan vijf jaar
- meer dan vijf jaar

Hoe regelmatig fietst u?

- minstens een keer per jaar
- minstens een keer per maand
- 1-2 keer per week
- 3-4 keer per week

5-7 keer per week

Hoe bekwaam zou u zeggen dat u bent in fietsen?

1 niet bekwaam
2 niet erg bekwaam
3 enigszins bekwaam
4 bekwaam
5 erg bekwaam

Voelt u zich over het algemeen veilig/comfortabel tijdens het fietsen?

1 erg onveilig
2 behoorlijk onveilig
3 enigszins veilig
4 veilig
5 heel veilig

In het tweede deel ziet u een reeks van 12 kruispunten die u kunt tegenkomen op de fiets in de stad Groningen. Elk scenario wordt weergegeven met een afbeelding uit google streetview en een top-down overzicht van het kruispunt.

Per kruispunt wordt u gevraagd uw ervaring van de veiligheid van dat kruispunt aan te geven. In elk scenario begint u bij de groene pijl en steek je de kruising rechtdoor over. In sommige scenario's kun je niet rechtdoor, hier steek je toch de kruising over en ga je linksaf.

Scenario X/12

<PICTURE>
Kruispunt gezien vanaf de kant van waaruit u nadert.

<ILLUSTRATION>
Bovenaanzicht van het kruispunt. De groene pijl geeft uw locatie in dit scenario aan.

Hoe veilig zou u zich voelen bij het oversteken van de kruising in het bovenstaande scenario?

1 erg onveilig
2 onveilig
3 enigszins veilig
4 veilig
5 heel veilig

U heeft het einde van de enquête bereikt.

Nogmaals dank voor uw medewerking.

Vragen en opmerkingen kunnen worden gericht aan S.R.van.Nieuwkuijk@student.rug.nl

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Appendix 6: statistical tests

6.1 ANOVA comparing perceived safety between types of intersections

MeanPerceivedSafety

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
type 1	19	2,5395	,34837	,07992	2,3716	2,7074	2,03	3,37
type 2	46	2,5020	,38174	,05628	2,3886	2,6153	1,67	3,30
type 3	35	2,3309	,35270	,05962	2,2097	2,4520	1,28	2,89
Total	100	2,4492	,37260	,03726	2,3753	2,5231	1,28	3,37

ANOVA

MeanPerceivedSafety

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,773	2	,387	2,890	,060
Within Groups	12,971	97	,134		
Total	13,745	99			

6.2 Independent samples t-test comparing perceived safety between type 2a and type 2b intersections

	Type	N	Mean	Std. Deviation	Std. Error Mean
MeanPerceivedSafety	type 2a	22	2,2555	,28221	,06017
	type 2b	24	2,7279	,31779	,06487

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
MeanPerceivedSafety	Equal variances assumed	,262	,612	-5,312	44	,000	-,47246	,08894	-,65172	-,29321
	Equal variances not assumed			-5,340	43,961	,000	-,47246	,08848	-,65078	-,29414

6.3.1 Nonparametric Kruskal-Wallis test comparing perceived safety between type 3a, type 3b and type 3c intersections

Kruskal-Wallis Test

Ranks

	Type	N	Mean Rank
MeanPerceivedSafety	type 3a	7	15,00
	type 3b	16	25,78
	type 3c	12	9,38
	Total	35	

Test Statistics[a,b]

	MeanPerceivedSafety
Kruskal-Wallis H	18,336
df	2
Asymp. Sig.	,000

a. Kruskal Wallis Test

b. Grouping Variable: Type

6.3.2 Pairwise post hoc Dunn's test between type 3a, type 3b and type 3c intersections

Pairwise Comparisons of Type

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
type 3c-type 3a	5,625	4,872	1,154	,248	,745
type 3c-type 3b	16,406	3,912	4,194	,000	,000
type 3a-type 3b	-10,781	4,643	-2,322	,020	,061

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is ,05.

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

6.4 Multiple linear regression model

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,749[a]	,561	,456	,27472

a. Predictors: (Constant), two way, Give-way markings, five legged, four lanes, Colored surface, SpeedBinary, three legged, Bike path, Lines indicating cyclists, Continued, Crosswalk, Crossing_Island, Curblane_Width, Uitrit, Crossing_Distance, two lanes, Raised intersection, White Boxes, Bike lane

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7,707	19	,406	5,375	,000[b]
	Residual	6,037	80	,075		
	Total	13,745	99			

a. Dependent Variable: MeanPerceivedSafety

b. Predictors: (Constant), two way, Give-way markings, five legged, four lanes, Colored surface, SpeedBinary, three legged, Bike path, Lines indicating cyclists, Continued, Crosswalk, Crossing_Island, Curblane_Width, Uitrit, Crossing_Distance, two lanes, Raised intersection, White Boxes, Bike lane

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	2,204	,187		11,784	,000
	SpeedBinary	-,107	,091	-,111	-1,178	,242
	Bike lane	-,021	,113	-,027	-,183	,855
	Bike path	-,019	,121	-,018	-,158	,875
	Continued	,511	,125	,662	4,097	,000
	Give-way markings	-,133	,086	-,178	-1,557	,123
	White Boxes	-,141	,112	-,160	-1,257	,212
	Lines indicating cyclists	-,114	,133	-,096	-,855	,395
	Uitrit	-,022	,081	-,028	-,266	,791
	Raised intersection	-,108	,184	-,074	-,586	,560
	Crossing_Island	-,300	,116	-,253	-2,575	,012
	Colored surface	-,073	,184	-,047	-,397	,692
	Crosswalk	-,063	,066	-,085	-,949	,345

	three legged	,051	,066	,067	,772	,443
	five legged	-,337	,292	-,091	-1,155	,251
	two lanes	,111	,145	,085	,760	,450
	four lanes	-,839	,229	-,317	-3,666	,000
	Curblane_Width	-,002	,036	-,005	-,053	,958
	Crossing_Distance	,021	,010	,238	2,072	,041
	two way	,196	,099	,215	1,969	,052

a. Dependent Variable: MeanPerceivedSafety

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
1	four legged	.[b]	.	.	.	,000
	one lane	.[b]	.	.	.	,000
	one way	.[b]	.	.	.	,000

a. Dependent Variable: MeanPerceivedSafety

b. Predictors in the Model: (Constant), two way, Give-way markings, five legged, four

6.5 Independent samples t-test comparing self-reported perception of cycling safety between males and females

Group Statistics

	Gender	N	Mean	Std. Deviation	Std. Error Mean
Self-reported safety perception of cycling	female	107	2,99	,807	,078
	male	201	3,13	,691	,049

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Self-reported safety perception of cycling	Equal variances assumed	,012	,912	-1,638	306	,102	-,144	,088	-,316	,029
	Equal variances not assumed			-1,562	189,531	,120	-,144	,092	-,325	,038

6.6 Independent samples t-test comparing self-reported cycling skill between males and females

	Gender	N	Mean	Std. Deviation	Std. Error Mean
Self-reported cycling skill	female	107	3,56	,703	,068
	male	201	3,75	,477	,034

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Self-reported cycling skill	Equal variances assumed	21,353	,000	-2,814	306	,005	-,190	,068	-,324	-,057
	Equal variances not assumed			-2,512	159,352	,013	-,190	,076	-,340	-,041

6.7.1 ANOVA comparing self-reported perceptions of cycling safety between age groups

Self-reported safety perception of cycling

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
19-34	115	3,25	,804	,075	3,10	3,40	0	4
35-44	23	3,17	,491	,102	2,96	3,39	2	4
45-54	37	3,19	,569	,094	3,00	3,38	2	4
55-64	77	2,83	,715	,081	2,67	2,99	0	4
65+	62	2,89	,791	,101	2,69	3,09	1	4
Total	314	3,06	,756	,043	2,98	3,15	0	4

ANOVA

Self-reported safety perception of cycling

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	11,044	4	2,761	5,088	,001
Within Groups	167,682	309	,543		
Total	178,726	313			

6.7.2 Pairwise post hoc Tukey's test, comparing self-reported perception of cycling safety between age groups

Dependent Variable: Self-reported safety perception of cycling

Tukey HSD

(I) Age	(J) Age	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
19-34	35-44	,078	,168	,990	-,38	,54
	45-54	,063	,139	,991	-,32	,45
	55-64	,421*	,108	,001	,12	,72
	65+	,365*	,116	,016	,05	,68
35-44	19-34	-,078	,168	,990	-,54	,38
	45-54	-,015	,196	1,000	-,55	,52
	55-64	,343	,175	,289	-,14	,82
	65+	,287	,180	,502	-,21	,78
45-54	19-34	-,063	,139	,991	-,45	,32
	35-44	,015	,196	1,000	-,52	,55
	55-64	,358	,147	,110	-,05	,76
	65+	,302	,153	,281	-,12	,72
55-64	19-34	-,421*	,108	,001	-,72	-,12
	35-44	-,343	,175	,289	-,82	,14
	45-54	-,358	,147	,110	-,76	,05
	65+	-,056	,126	,992	-,40	,29
65+	19-34	-,365*	,116	,016	-,68	-,05
	35-44	-,287	,180	,502	-,78	,21
	45-54	-,302	,153	,281	-,72	,12

Comfort

Tukey HSD[a,b]

Age	N	Subset for alpha = 0.05: 1	2
55-64	77	2,83	
65+	62	2,89	2,89
35-44	23	3,17	3,17
45-54	37	3,19	3,19
19-34	115		3,25
Sig.		,137	,123

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 46,161.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

6.8.1 ANOVA comparing self-reported cycling skill between age groups

Self-reported cycling skill

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
19-34	115	3,68	,615	,057	3,56	3,79	1	4
35-44	23	3,52	,947	,198	3,11	3,93	0	4
45-54	37	3,89	,315	,052	3,79	4,00	3	4
55-64	77	3,73	,448	,051	3,63	3,83	3	4
65+	62	3,53	,535	,068	3,40	3,67	2	4
Total	314	3,68	,573	,032	3,61	3,74	0	4

ANOVA

Self-reported cycling skill

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3,756	4	,939	2,927	,021
Within Groups	99,111	309	,321		
Total	102,866	313			

6.8.2 Pairwise post hoc Tukey's test, comparing self-reported cycling skill between age groups

Multiple Comparisons

Dependent Variable: Skill

Tukey HSD

(I) Age	(J) Age	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
19-34	35-44	,157	,129	,746	-,20	,51
	45-54	-,214	,107	,270	-,51	,08
	55-64	-,049	,083	,977	-,28	,18
	65+	,146	,089	,475	-,10	,39
35-44	19-34	-,157	,129	,746	-,51	,20
	45-54	-,370	,150	,102	-,78	,04
	55-64	-,206	,135	,546	-,57	,16
	65+	-,011	,138	1,000	-,39	,37
45-54	19-34	,214	,107	,270	-,08	,51
	35-44	,370	,150	,102	-,04	,78
	55-64	,165	,113	,594	-,15	,48
	65+	,360*	,118	,020	,04	,68
55-64	19-34	,049	,083	,977	-,18	,28
	35-44	,206	,135	,546	-,16	,57
	45-54	-,165	,113	,594	-,48	,15
	65+	,195	,097	,260	-,07	,46

65+	19-34	-,146	,089	,475	-,39	,10
	35-44	,011	,138	1,000	-,37	,39
	45-54	-,360*	,118	,020	-,68	-,04
	55-64	-,195	,097	,260	-,46	,07

*. The mean difference is significant at the 0.05 level.

Skill

Tukey HSD[a,b]

Age	N	Subset for alpha = 0.05 1	2
35-44	23	3,52	
65+	62	3,53	
19-34	115	3,68	3,68
55-64	77	3,73	3,73
45-54	37		3,89
Sig.		,409	,368

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 46,161.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

6.9 Nonparametric Mann-Whitney test comparing self-reported perception of cycling safety between Dutch and non-Dutch cyclists

	Cultural background	N	Mean Rank	Sum of Ranks
Self-reported safety perception of cycling	Dutch	286	160,93	46025,50
	Non Dutch	28	122,48	3429,50
	Total	314		

Test Statistics[a]

	Self-reported safety perception of cycling
Mann-Whitney U	3023,500
Wilcoxon W	3429,500
Z	-2,393
Asymp. Sig. (2-tailed)	,017

a. Grouping Variable: Cultural background

6.10 Nonparametric Mann-Whitney test comparing self-reported cycling skill between Dutch and non-Dutch cyclists

Ranks

	Cultural background	N	Mean Rank	Sum of Ranks
Self-reported cycling skill	Dutch	286	163,68	46812,00
	Non Dutch	28	94,39	2643,00
	Total	314		

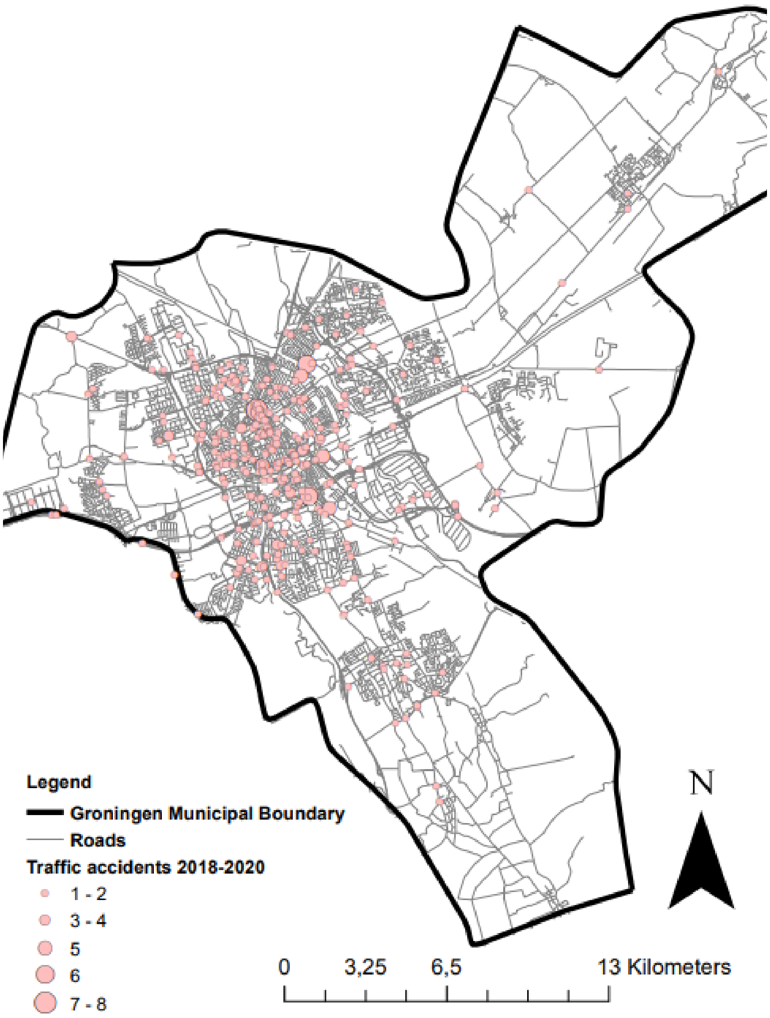
Test Statistics[a]

	Self-reported cycling skill
Mann-Whitney U	2237,000
Wilcoxon W	2643,000
Z	-4,898
Asymp. Sig. (2-tailed)	,000

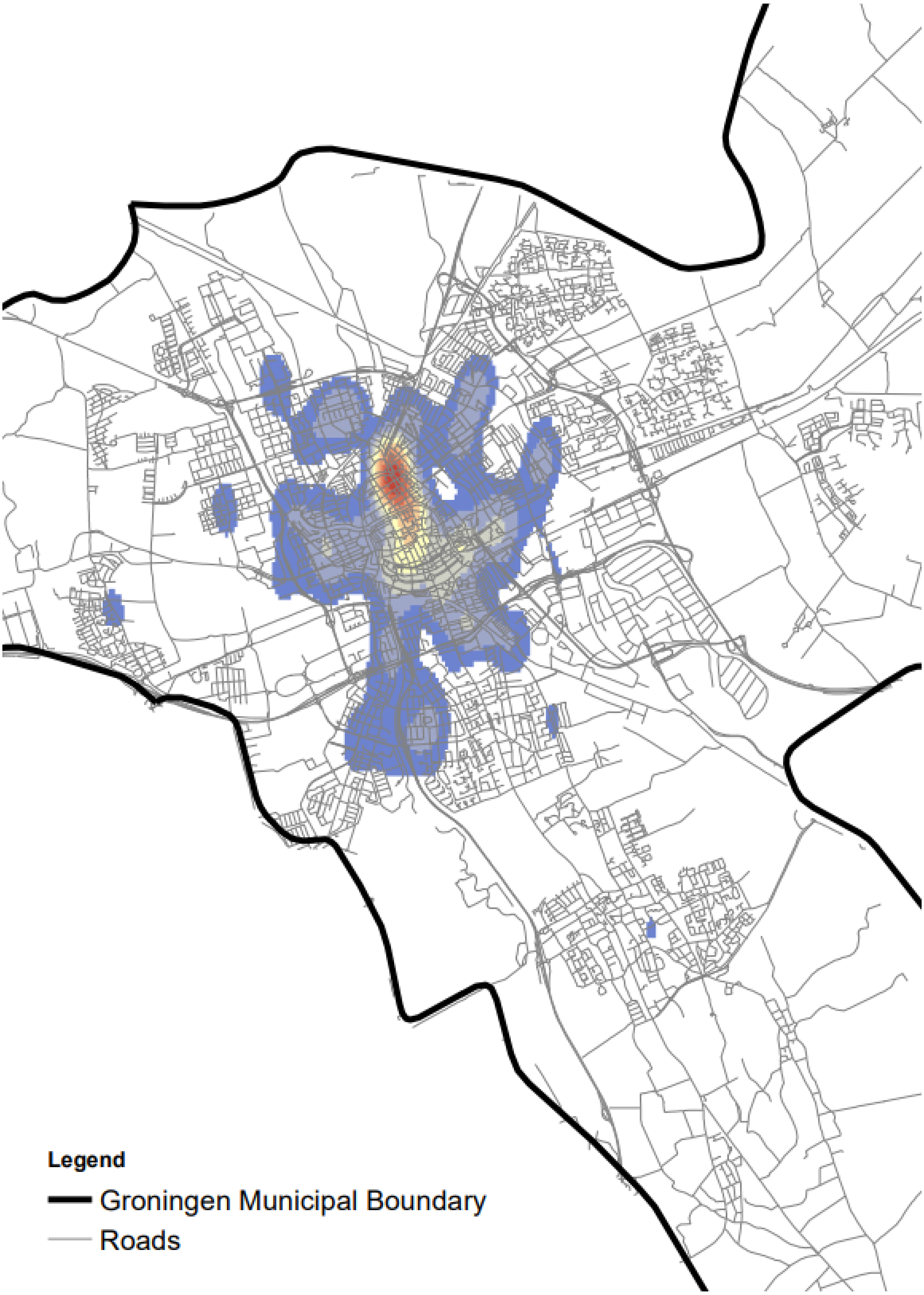
a. Grouping Variable: Cultural background

Appendix 7: GIS analyses and maps

7.1 Traffic accidents involving at least one cyclist in 2018, 2019 and 2020 in the municipality of Groningen

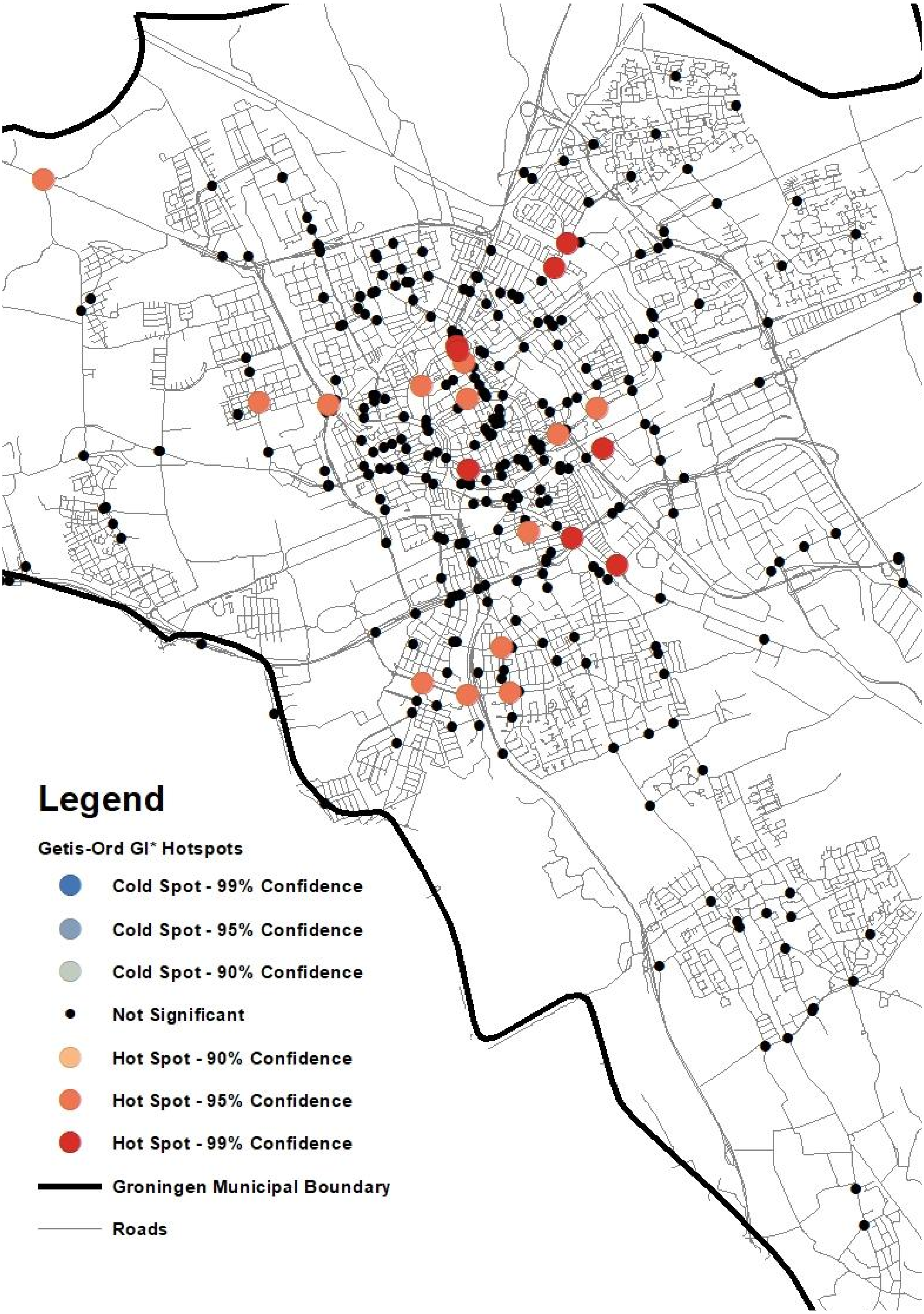


7.2 Kernel density heatmap of traffic accidents involving cyclists

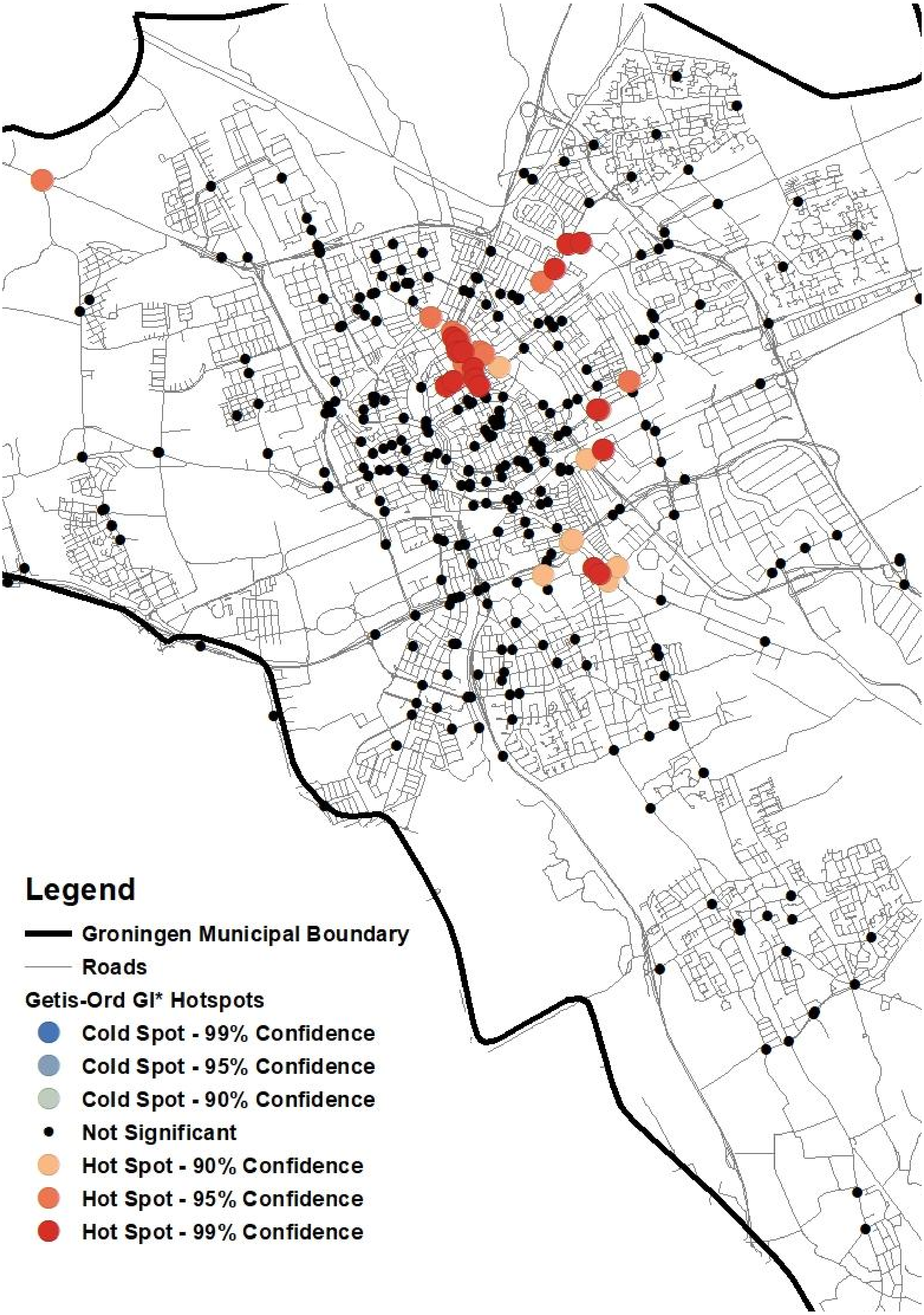


7.3 Point density heatmap of traffic accidents involving cyclists

7.4 Getis-Ord Gi* hotspot analysis of traffic accidents involving cyclists based on inverse distance



7.5 Getis-Ord Gi* hotspot analysis of traffic accidents involving cyclists based on a fixed distance of 500



7.6 Map of selected intersections