Master thesis

The traffic safety of bicycle streets in the Netherlands

Rick Delbressine

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“ Zie kwam op de fiets veurbeej,
en lachte teage meej.
Dat roeje klied, dat roeje mond,
ich stond vastgenageld aan de grond.
Ich kleurde langzaam in de zon,
de lente die begon.”

’t Roeje Klied – Rowwen Hèze

SAMENVATTING

Dit onderzoek is uitgevoerd om de verkeersveiligheid van fietsstraten in Nederland in kaart te brengen. Aanleiding voor dit onderzoek is het groeiend aantal fietsstraten in Nederland, terwijl slechts beperkte kennis over deze fietsstraten beschikbaar is. Het onderzoek is gebaseerd op het idee dat functie, ontwerp en gebruik van een straat elkaar beïnvloeden. Dit onderzoek is opgedeeld in drie onderzoeksstappen. In elke onderzoeksstap wordt één van de drie aspecten nader uitgezocht. Hiervoor zijn acht Nederlandse fietsstraten geselecteerd, vier fietsstraten met een middengeleider en vier fietsstraten met fietsers meer in het midden van de straat. Dit is gedaan om beide veelvoorkomende typen fietsstraten te kunnen vergelijken.

In de eerste onderzoeksstap zijn de mogelijke functies van fietsstraten bepaald met behulp van een literatuuronderzoek. Het resultaat was een theoretisch raamwerk, waarmee de functies van de acht geselecteerde fietsstraten gevonden kunnen worden. De stroomfunctie voor fietsers en erftoegangsfunctie voor gemotoriseerd verkeer komen naar voren als de belangrijkste functies van een fietsstraat. Deze functies zijn tegenstrijdig en vormen een bron van conflicten tussen motorvoertuigen en fietsers.

Met behulp van telslangen en verkeersobservaties is in de tweede onderzoeksstap het rijgedrag op de acht geselecteerde fietsstraten onderzocht. De door de telslangen gegenereerde data gaf informatie over de snelheid en voertuigcategorie van het passerende voertuig. De observaties zijn gebruikt om het rijgedrag, de positie op de weg en mogelijke conflicten van weggebruikers van de fietsstraat te onderzoeken. Dit onderzoek maakte duidelijk dat een groot deel van de auto's zich niet houdt aan de veilige snelheidslimiet van 30 km/u. Verder laat het onderzoek zien dat niet de ratio fietsers/motorvoertuigen bepalend is voor de snelheid van auto's op de fietsstraat, maar dat de breedte van de fietsstraat een grote invloed op de fietsstraat heeft. Ook is geconcludeerd dat voertuigen die parkeren of stoppen op de fietsstraat een gevaarlijk obstakel zijn voor fietsers. Als de erftoegangsfunctie sterk aanwezig is in de straat, zullen er meer voertuigen parkeren en stoppen op de straat. De erftoegangsfunctie moet daarom relatief onbelangrijk zijn, vergeleken met de stroomfunctie voor fietsers. Door middel van een interview is verder nog kennis met betrekking tot Human Factors in verkeer geïntegreerd in het onderzoek. Dit is gedaan om de herkenbaarheid van fietsstraten te onderzoeken.

De resultaten van deze twee onderzoeksstappen zijn gebruikt om de twee types fietsstraten te testen aan de Duurzaam Veilig principes functionaliteit, homogeniteit, voorspelbaarheid en vergevingsgezindheid. De belangrijkste conclusie van deze test is dat fietsstraten zoveel verschillende verschijningsvormen hebben dat ze niet herkenbaar zijn voor de weggebruiker. Het wegverloop van de fietsstraat en het weggedrag van verkeer op de fietsstraat is daarom moeilijk te voorspellen. De herkenbaarheid en voorspelbaarheid kunnen verbeterd worden door één standaard ontwerp toe te passen, opgebouwd uit herkenbare ontwerpelementen. De homogeniteit van het verkeer kan verbeterd worden door de snelheid van motorvoertuigen te reduceren. Met betrekking tot de functies van een fietsstraat kan geconcludeerd worden dat de mix van functies de oorzaak is van veel conflicten op de fietsstraat. Deze mix van functies vereist aandacht voor de vergevingsgezindheid van de infrastructuur en de gebruikers.

Aanbevelingen voor het ontwerp van nieuwe fietsstraten zijn opgesteld in de ontwerpstap. De keuze voor een fietsstraat met fietsers meer in het midden als standaardontwerp, het toevoegen van fietspadmarkering en de toepassing van kruispuntplateaus om de snelheid te reduceren zijn de belangrijkste aanbevelingen. Verder is het aanbevolen om de goot te integreren met de rabatstrook om zo het gebruik van de rabatstrook te ontmoedigen. Tot slot zou er één standaard verkeersbord voor fietsstraten ingesteld moeten worden.

De onderzochte steekproef van acht fietsstraten is te klein om significante conclusies te kunnen trekken. De studie geeft wel richtingen aan voor verder onderzoek met het oog op een herziening van de ontwerprichtlijnen voor fietsstraten. Een uitgebreider onderzoek met een grotere steekproef is nodig om de conclusies in dit onderzoek te valideren.

ABSTRACT

The goal of this research was to study if bicycle streets as applied in the Netherlands are traffic safe. The main motivation for this research was the growing number of bicycle streets in the Netherlands, while so far less is known about the traffic safety of those streets. This research was based on the theory that function, design and behaviour of a street and traffic on a street influence each other. The research was split up in three research steps, each focussing on one of the aspects. Those aspects have been studied for eight bicycle streets in the Netherlands, four single-lane and four two-lane bicycle streets. The selection of two different designs made it possible to compare the two common types of bicycle streets.

In the first step, the possible functions of bicycle streets have been determined by a literature review. This resulted in a theoretical framework for finding the functions of the eight bicycle streets. The study of the functions shows that the most important functions of the bicycle street are the flow function for cyclists and the access function for motor vehicles. Those functions are conflicting and therefore a source for conflicts between motor vehicles and cyclists on the bicycle street.

In the second step, the driving behaviour on the eight selected bicycle streets was investigated by collecting data via road tube counters and observing the traffic on the bicycle streets. The data collected by the road tube counters provided information about the speed and type of the vehicle passing. The observations gave information about the behaviour, position on the road and possible conflicts of road users on the bicycle street. The results of this step showed that a large part of the cars drive faster than the safe speed limit of 30 km/h on the bicycle street. Further was concluded that the ratio cyclists/motor vehicles does not influence the speed of motor vehicles on the bicycle street, but that the width of the profile has a big influence on the speed. Also has been concluded that vehicles parking or stopping on the bicycle street are a serious obstacle for cyclists. The stronger the access function of the street is present, the more vehicles are parking and stopping on the street. The access function of the street should therefore be relatively unimportant compared with the flow function for cyclists. By the use of an interview, knowledge about Human Factors in traffic has been used to test the recognisability of the designs.

Based on those two research steps, the outcomes have been tested to the Sustainable Safety principles functionality, homogeneity, predictability and forgivingness. The most important conclusion that has been drawn from this test is that bicycle streets have so many appearances that they are not recognisable for the different road users. The road course of the bicycle street and the driving behaviour of road users on the bicycle street are therefore difficult to predict. The recognisability and predictability can be improved by applying one standard design with recognisable design elements. The homogeneity of the traffic flow could be improved by reducing the speeds of motor vehicles on the street. When the functionality is considered, there can be concluded that the mix of functions causes conflicts, but is at the same time the main characteristic of a bicycle street. To deal properly with this mix of functions, the street and its users should be forgiving.

In the design step, recommendations have been made for the design of new bicycle streets. Important recommendations are the choice for single-lane bicycle streets as standard design, adding bicycle path lining to those type of streets and the application of raised intersections to reduce the speeds of motor vehicles on the bicycle street. Further has been recommended to integrate the gutter with the rabat strip to clarify the function of the rabat strip and it is recommended to apply one standard traffic sign on all the bicycle streets in the Netherlands.

Although the sample of eight bicycle street is too small to draw significant conclusions that could lead to a revision of guidelines, the study indicates some aspects that need further investigation. A more extensive research with a larger sample is needed to validate many conclusions that are drawn in this study.


fietsstraat
auto te gast
Heidetuin
Heidetuin

PREFACE

The master thesis has been written as final work for the master study Civil Engineering at the Delft University of Technology. This research has been done at the department of Transport & Planning, within the educational chair of Traffic Safety. From January till July, I have been working on the subject of the traffic safety of bicycle streets. A subject that is not directly considered as sexy or cool, but that has certainly its charming parts. Especially the fact that it is a really concrete and tangible subject, enthuses me during the process.

At this place, I want to thank all the people who have supported me during the process. In the first place I want to thank my colleagues at Grontmij for supporting and facilitating my research. A special thank to my daily supervisor at Grontmij, Erik Mansvelder, who often provided me with a practical view on the working field, but also helped to structure my thoughts and ideas in simple schemes. I want also thank Atze Dijkstra of SWOV, for his critical and fast feedback and suggestions, especially regarding my theoretical research and the interpretation of the collected data. Further a special thank to professor Fred Wegman, who was especially critical on the process and research design and provided me with several supportive suggestions. Furthermore I want to thank Remon Rooij from the faculty of Architecture for his critical view and good suggestions. He triggered me to pay also attention to the urban planning aspects of traffic safety and road design. I want also thank Paul Wiggenraad for his practical suggestions in the process.

Furthermore I want to thank all the traffic engineers of the municipalities of the eight selected bicycle streets, who supported me by providing me with information by interviews, articles and drawings of the bicycle streets. Those are Niel Klein from the municipality of Alkmaar, Bram Rodenburg of the municipality of Castricum, Job Punt, Jan Nederveen and David Polman of the municipality of Delft and Marius van Galen of the municipality of Zoetermeer. Furthermore have I have been provided with information by Pau Tjioe Kho of the municipality of Haarlem, Jelger de Haas of the municipality of Houten, Menno Bovens of the municipality of Oss and Ilse Bloemhof of the municipality of Zwolle. Also the local department of the Dutch cyclist's union in Zwolle has provided me with a valuable evaluation of the bicycle street at the Vondelkade.

Last, I want to thank Jasper Keij for critical reviewing my thesis. Also my girlfriend Maud, who reviewed all my chapters and provide them with supporting critics. Further, I want to thank my parents for their support and critics during the whole process.

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1 INTRODUCTION

In this chapter, an introduction in the research is given. In section 1.1 bicycle streets in the Netherlands are shortly described. The next section provides the definition for bicycle streets that is used in this research, followed by the functional requirements for bicycle streets. The intended behaviour of drivers on bicycle streets is described in section 1.4. In section 1.5, the state of the research is presented, followed by the problem analysis and description of this research. Also the research design and limitations of the research are described in this chapter. The outline of the rest of the thesis is described below.

The second chapter describes the different possible traffic functions which a bicycle street has. This is done by describing the position of the bicycle street in the urban environment and the bicycle network, but also by describing developments in the traffic safety of cyclists and the role bicycle streets probably could play in the improvement of traffic safety of cyclists. The insights that are provided by this literature study have lead to a theoretical framework for the analysis of the selected bicycle streets. In the third chapter is the analysis of the selected bicycle streets described. The analysis has lead to three schemes, illustrating the different functions per bicycle street. Based on this analysis, conclusions about the different functions of the bicycle streets have been drawn. In the fourth chapter, the driving behaviour on the bicycle streets is analysed. Based on observations and traffic counts the driving behaviour of motorized vehicles, mopeds and cyclists on the bicycle street have been studied.

In the fifth chapter, the findings about the functions of bicycle streets and the behaviour on bicycle streets have been tested to the principles of Sustainable Safety. The outcomes of this chapter were the base of the review of the design in chapter six. In the sixth chapter, the designs have been evaluated and the existing guidelines have been reviewed. Based on the evaluation and the review of the existing guidelines, recommendations are made about the design of bicycle streets.

In the seventh chapter, the conclusions of the research are formulated, followed by the recommendations in chapter eight. In the ninth chapter, the outcomes of the research are discussed. In the appendices, the complete function analysis of the selected bicycle streets is given. Further, the descriptions of the observations, together with the analysis of the traffic data can be found in an appendix. Also the interviews with road authorities (in Dutch) are included in an appendix.

1.1 BICYCLE STREETS IN THE NETHERLANDS

Bicycle streets have been developed to accommodate main bicycle routes on streets within residential areas. On those streets, the volume of cyclists is that large that cyclists are the main users of the street. To accommodate this large volume of cyclists, bicycle amenities are needed. Within the existing urban areas, often no space is available to create those facilities. Bicycle streets provide a bicycle amenity within the space of an existing street. Reasons to apply a bicycle street are facilitating a large volume of cyclists on a main bicycle route, filling up a missing link between two already existing bicycle amenities or visually continuing of the main bicycle route within residential areas. In new areas, bicycle streets are applied to save space and therewith costs.

After some experiments in the 70's of the previous century, the bicycle street had its real breakthrough in the Netherlands in the mid-nineties. In 1994, Grontmij proposed a design for a bicycle street, containing a median to enforce cars to anticipate on the cyclists (Meijboom & Prikken, 1994). Two years later, a new, more flexible design for a bicycle street has been developed by Andriesse and Hansen (1996). Those two designs have been adapted by road authorities and evolved over the years towards to common designs of bicycle streets in the Netherlands: the single-lane bicycle street and the two-lane bicycle street. Those designs in practice are shown in Figure 1 and Figure 2.

FIGURE 1: A SINGLE-LANE BICYCLE STREET IN ZWOLLE (SOURCE: FIETSBERAAD.NL)

FIGURE 2: A TWO-LANE BICYCLE STREET IN OSS (SOURCE: FIETSBERAAD.NL)

Those designs have in common that they both take cyclists as base for the design. A red coloured pavement emphasizes the special position of cyclists on this street and the small driving strip should contribute to low speeds of cars.

The main difference between those variants is that a single-lane bicycle street is more flexible than a two-lane bicycle street. The median could be an obstacle for cyclists to pass. Therefore, faster cyclists will have to stay behind slower cyclists using the full width of the driving strip. The single-lane bicycle street design provides more flexibility in the way that faster cyclists could more easily overtake slower cyclists since there is no median.

Since the guidelines for bicycle streets such as in the ASVV 2012 keep a lot of freedom in their recommendations, the implementations differ from street to street. However, some general dimensions that are used for bicycle streets could be given, based on existing designs. Figure 3 shows a cross-sectional profile of a single-lane bicycle street. This design is characterized by a small, red coloured driving strip in the middle of the road with a dimension of 3 to 3.5 meter. This is comparable with the dimension for a two way cycle track (CROW, 2012). On both sides along the driving strip, rabat strips are applied to provide also enough space for cars. Those rabat strips have a different texture and colour than the driving strip to make clear that cyclists should cycle on the driving strip and not on the rabat strips.

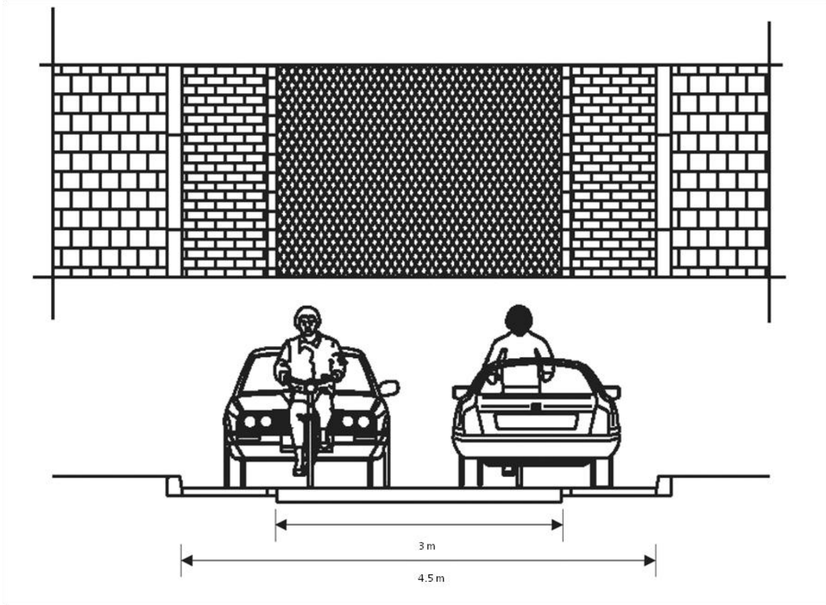


FIGURE 3: CROSS-SECTIONAL PROFILE OF A SINGLE-LANE BICYCLE STREET (CROW, 2007)

A cross-sectional profile of a two-lane bicycle street is given in Figure 4. The driving strips have a dimension of 2 to 2.5 meter. The median has a width of 0.5 to 1 meter and it is often possible to drive over the median. If parking spaces are located along the bicycle street, extra safety space is necessary between the driving strip and the parking spaces. This is often done by applying a smaller driving strip and a rabat strip between the parking spaces and the driving strip.

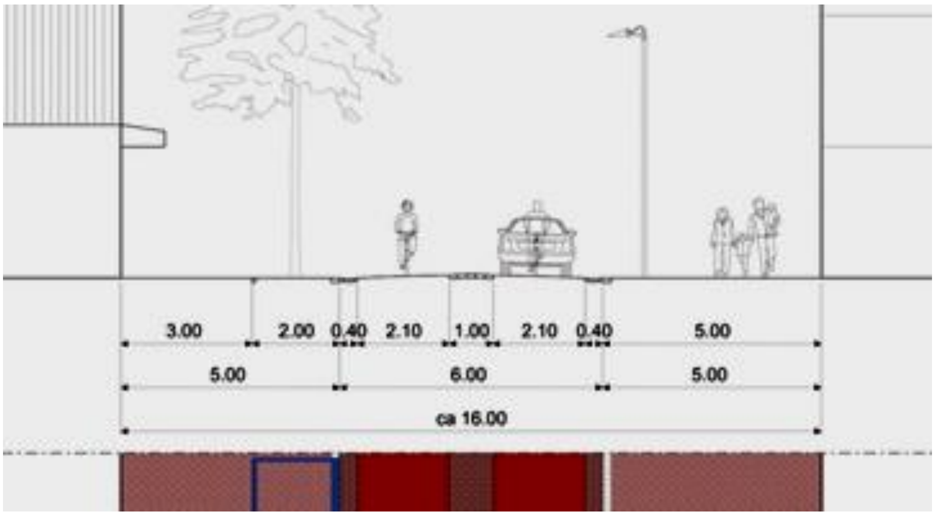


FIGURE 4: CROSS-SECTIONAL PROFILE OF A TWO-LANE BICYCLE STREET (SOURCE: BGSV.NL)

1.2 DEFINITION

In Fietsberaad publication no. 7, Rico Andriesse and Dirk Ligtermoet (2005) investigated the possibilities for bicycle streets in main bicycle routes. They took the function as point of view in defining the term bicycle street, instead of a design point of view. The definition they used is the following:

A bicycle street is an access road, part of a main bicycle route, designed in such way that its function is recognizable and clear for all road users, but also accessible for a limited amount of local motorized traffic. An important characteristic of a bicycle street is that cyclists are the most important users of the bicycle street.

Meijboom and Prikken (1994) have developed a design proposition for a bicycle street with two driving strips for cyclists mixed with cars. The driving strips are divided by a median. They developed this design, because they were facing a problem with access roads without bicycle amenities, having more bicycle users than car users but designed for car users. From the perspective that the road design should focus on the most important road user, they developed a bicycle street design as a design for streets with more cyclists than cars. From their ideas, a bicycle street could be defined as follows:

A bicycle street is a street, categorized as an access road, part of a main bicycle route and will be used by more cyclists than cars. The design of the street has been adjusted to large volumes of cyclists and give cyclists a prominent position on the street. Since cyclists are the main users of the street, car drivers should adjust their behaviour to the cyclists.

Those definitions slightly differ from each other. The definition of Andriesse and Ligtermoet states that the function of the bicycle street should be clear. They probably mean its function being part of a main bicycle route. However, a bicycle street has more functions than only being part of a main bicycle route. Meijboom and Prikken state that it is important to give cyclists a prominent position on the street.

In the second definition the small amount of local motorized traffic is not emphasized. This is namely not a characteristic of a bicycle street, but a characteristic of an access road (SWOV, 2010b). This small amount of traffic should follow from the function of the street and is not restricted by a maximum volume of motorized vehicles. The second definition does also clearly state that car drivers should adjust their behaviour to the cyclists on the street, since the cyclists are the most important users of the street. The first definition only addresses that cyclists are the most important users, but does not translate this into behaviour.

Based on those arguments, the second definition will be used in this study on the traffic safety of bicycle streets.

1.3 Functional requirements

Designing attractive and safe bicycle streets is only possible if some functional requirements are met in the design. In CROW publication 230 "Design manual for bicycle traffic" (CROW, 2007) five requirements for high quality bicycle routes are mentioned. Those requirements are continuity, directness, safety, comfort and attractiveness.

Continuity
A bicycle route should be continuous. Cyclists should never have to search for the other part of the route. Also the bicycle amenities along the route should be continuous, missing links could seriously reduce the attractiveness of the route.

Directness
A bicycle route should provide one of the shortest or fastest routes from origin to destination. Cyclists are sensitive for detours and are therefore not willing to take a large detour for a more attractive bicycle route (Caulfield, Brick & McCarthy, 2012).

Safety
Bicycle routes should provide a safe route for cyclists by having separated bicycle tracks, bicycle lanes or other cycle amenities. At mixed profiles, the speed of motorized traffic may not be higher than the safe speed limit of 30 km/h (Wegman & Aarts, 2006). On bicycle streets only local motorized traffic with its origin or destination directly along the street should be facilitated. The dominant position of the cyclists will be at risk when the intensity of motorized traffic becomes too high.

Parking facilities along bicycle streets could be dangerous since opening doors of cars could seriously injure cyclists. Enough space between parking and the bicycle facility is therefore recommended. Parking on bicycle streets should be prevented.

Furthermore, attention should be paid to the design and safety of the intersections between the bicycle street and busier access roads and distributor roads. Also the visibility and lightning at the bicycle street require some extra attention since good visibility of cyclists increases both the traffic safety and social safety of cyclists on the bicycle street.

The last topic regarding safety is the pavement of the bicycle street. The pavement should be smooth and in good condition. Holes, cracks and rutting of the pavement will not only decrease the comfort, but also the safety for cyclists on the street. Several studies have shown that cyclists tend to keep away from roads with bad pavement (Andriesse & Hansen, 1996).

Comfort
Bicycle routes should be comfortable for cyclists. A certain level of comfort could be achieved by giving the bicycle route priority, also in residential areas. Another aspect that increases the comfort is a flat route, without high speed bumps, steep hills for tunnels, bridges or a dike. The route should also be fluent, without sharp curves or strange manoeuvres (CROW, 2007).

Attractiveness
The condition attractiveness of public space for cyclists is divided into three sub conditions (Scheltema, 2012). The first sub condition is maintenance. A bicycle street should be maintained well to stay attractive for bicyclists. Cracks in the pavement should be repaired as soon as possible, but also green areas and lightning along the bicycle street should be maintained. The second and third conditions are related to each other, liveliness and experience. There should be activities along the public space for bicyclists to guarantee liveliness along the route. Liveliness and a proper design of the route will contribute to the experience cyclists have on the bicycle route (Scheltema, 2012). However, one could argue whether liveliness along the street fits within the categorization as access road, since traffic is often an important source of liveliness.

1.4 Intended use and behaviour

1.4.1 Intended use in networks

Bicycle streets are developed to facilitate main bicycle routes through residential areas. They should provide a direct, fast and safe route for cyclists between origins and destinations.

Bicycle streets should be streets within those main bicycle routes without bicycle facilities and no space available for separate bicycle facilities. They provide an attractive, direct and safe bicycle facility within the existing built-up area.

A main bicycle route could consist of only bicycle streets, but could also contain other designs where the bicycle street provides a facility at a missing link. Bicycle streets could also be used to create an attractive alternative route for a route along a distributor road.

1.4.2 Intended behaviour on bicycle streets

The behaviour of traffic users on the bicycle street as intended by traffic engineers is described in this paragraph. This intended behaviour has been defined based on the outcomes of a brainstorm session with several traffic engineers. Each traffic engineer has been involved in the design of bicycle streets in the past.

In the brainstorm session, the general intention of bicycle streets has been discussed, but also the differences between the two studied designs have been discussed. The results of this brainstorm session were some clear statements about the intended behaviour of different users on the bicycle street.

The first general statement that has been conducted from this session is that the day volume of cyclists should be larger than the day volume of motorized traffic. Cyclists are therefore the dominant users of the bicycle street during a large part of the day and the design should strengthen this dominant position. When there are less cyclists on the street, car drivers should still have the feeling that they are using a bicycle facility in the first place. Motorized vehicles have to anticipate on the cyclists on the street by adjusting their speed. To enforce a low speed for motorized vehicles, motorized vehicles have to stay behind the cyclists.

However both designs have the same main goal, they differ in the way they try to reach this goal. The two-lane bicycle street design aims on enforcing cars to stay behind the cyclist. Passing the median to overtake the cyclist should only take place when a car is following a cyclist over a long time and no traffic in the opposite direction is approaching. The median should provide a resistance for the car driver to overtake the cyclist in front of him.

The single-lane bicycle street design provides more flexibility to the road users. In this design faster cyclists could more easily overtake slower cyclists than in the two-lane bicycle street design since they do not have to pass the median. Cyclists have to cycle on the asphalt strip in the middle of the road, cars have to stay behind them.

Another difference between those two bicycle street designs is that the single-lane bicycle street aims not only on a change in behaviour of cars, but also of cyclists by positioning them more in the middle of the road instead of on the right side of the road. The idea is that both users classes have to anticipate on each other with a better traffic safety as result. In the two-lane bicycle street design, cyclists keep their natural position on the road and only cars have to anticipate.

Vehicles parked on the street could be unexpected obstacles for cyclists and therefore be dangerous. Parked cars conflict with the flow function for cyclists. Therefore cars should not be parked on the street.

Special attention needs to be paid to mopeds on the bicycle street. On distribution roads within the built-up area, mopeds are driving on the carriageway since the speed differences with cyclists are often too high to mix them on the bicycle path (Hagenzieker, 1995). Since bicycle streets are not exclusive for cyclists, mopeds will be mixed with cyclists. To achieve a homogenous traffic flow, speed differences should be small, so mopeds should drive at the same speeds as cyclists.

To support the flow function for cyclists on the bicycle street, the bicycle street should have priority when crossing another street. It should also be clear for traffic on the crossing street that they are entering or crossing a bicycle street.

Based on this interview could be concluded that an ideal bicycle street is a domain of cyclists and therefore comparable with a bicycle path. If a bicycle path cannot be applied because parcels along the street need to be accessible via the street, a bicycle street can provide a good solution. The ideal intended behaviour can therefore shortly be reformulated. Cyclists should behave like they are cycling on a bicycle path: maximum of two cyclists next to each other, passing is possible with anticipation on approaching traffic. Local motorized traffic is allowed to enter the bicycle street at a low speed. They should have the feeling that they are using a bicycle facility and therefore should anticipate on the cyclists on the street. Through-going mopeds should not be present at the bicycle street, since the speed difference with cyclists is often high. Local mopeds are allowed, providing that they drive at a low and safe speed on the bicycle street.

1.5 State of the research

At this moment, most of the research on bicycle streets has focused on the design and implementation of bicycle streets in the Netherlands.

As stated in the previous section, the designs of the modern bicycle streets have been developed in the mid-nineties by Grontmij (Meijboom & Prikken, 1994) and Rico Andriesse (Andriesse & Hansen, 1996). In 2005, Rico Andriesse and Dirk Ligtermoet studied, commissioned by Fietsberaad, the possibilities for the implementation of bicycle streets in the Netherlands. They defined bicycle streets based on their function and provided some tools for road authorities and designers of bicycle streets.

Exact figures about the number of bicycle streets and kilometres of bicycle streets in the Netherlands are not available, but based on an internet search and field trips, the number of bicycle streets is estimated on a couple of hundred with an average length of one kilometre. In some municipalities several bicycle streets could be found, while in many other municipalities no bicycle streets could be found. Bicycle streets are still quite rare in the Netherlands, and only a small part of all the traffic participants in the Netherlands knows the existence of bicycle streets.

Some of the municipalities that have built bicycle streets have evaluated the bicycle streets within their municipality (Diepstraten, 2012; Fietsersbond Zwolle, 2005; Kho, 2006; Megaborn, 2005). Some of those evaluations have also been made available for the public. In 2005, engineering and consultancy agency Megaborn was commissioned by the municipality of Oss to evaluate the bicycle streets on the main bicycle routes in Oss (Megaborn, 2005). This evaluation consisted of a survey among users and residents, traffic counts, acoustic tests and a small route research. The outcomes of this study showed that the volume of cyclists has grown, while the volume of cars has diminished after realisation of the bicycle streets on the main bicycle routes. Cars are using parallel routes, since on the bicycle street the volume of cyclists is rather large and a part of the route has been reconstructed into a one-way-street. Cyclists are satisfied about the comfort of the bicycle street, however some intersections in the bicycle street need some attention. The priority for the bicycle street is not clear for traffic crossing the bicycle street and causes dangerous situations. There is also a certain tension between car users and cyclists, both are not satisfied with each other's behaviour.

The bicycle street in Oss has been evaluated again in 2012 (Diepstraten, 2012). In this evaluation study, almost ten year of experience with the bicycle street has been evaluated by an intern of the municipality of Oss. This evaluation is based on several traffic studies that have been carried out during the last ten years and a questionnaire, carried out among users of the bicycle street, both cyclists and residents. This evaluation showed that the volume of bicycle traffic on the bicycle street has been doubled since the opening of the bicycle street. A questionnaire has been carried out among cyclists on the bicycle street and residents: 23% of the respondents says that he or she has made more cycle kilometres due to the realisation of the bicycle street. 33% of the respondents says that he or she has more often chosen the bicycle instead of the car than before the realisation of the bicycle street. 82% of the respondents like to cycle on the bicycle street, since the bicycle street provides a comfortable route to the city centre. The number of crashes has also been decreased compared with the situation before the realisation of the bicycle street. A large part of those crashes occurred due to unclear priority situations at intersections and poles in the street creating a cut for motorized traffic.

Another evaluation has been carried out by the municipality of Haarlem in 2006. Pau Tjioe Kho (2006) evaluated the first bicycle street in Haarlem by carrying out a questionnaire among residents and users of the Venkelstraat. The results were mostly positive, especially among cyclists that use the bicycle street. Car users were negative about the bicycle street and it was not always clear to them that cyclists should cycle in the middle of the road and cars should stay behind them. This indistinctness should lead to irritations between cyclists and car drivers, according to the reactions of the respondents.

Also the Vondelkade in Zwolle has been evaluated by a questionnaire among members of the local department of the Dutch Cyclists' Union and residents of the houses along the Vondelkade (Fietsersbond Zwolle, 2005). The main conclusions of this evaluation were that the bicycle street is not recognizable by the traffic participants, cyclists have a ‘pushed’ feeling due to the cars behind them and mopeds drive too fast on the bicycle street.

Cyclists on the Vondelkade state that it is not clear to them that they have to cycle in the middle of the road and cars have to stay behind them.

The evaluations that are discussed are in essence based on small questionnaires carried out among users and residents of the bicycle streets. The evaluations give information about the experiences of residents and cyclists on the bicycle street, often in the begin stadium of the bicycle street. The evaluations do not give a good overview of the driving behaviour on the bicycle street. The quality of the evaluations is not that good, since the number of respondents is often small. The evaluations further focus mainly on local aspects of the bicycle street and do not provide information about the bicycle street in comparison with other bicycle streets. The evaluations do not give a good insight in whether the driving behaviour on the bicycle streets matches with the intended behaviour.

An important development in traffic safety is the growth of the number of crashes with cyclists involved over the last years. This happened while the number of other crashes without cyclists involved has been decreasing (Wijlhuizen, Goldenbeld, Kars & Wegman, 2012). Especially the number of seriously injured victims in these crashes has been increasing as well as the number of crashes with only non-motorized vehicles involved. Most of those crashes were cyclist-only crashes. This development has triggered the SWOV to come up with a new view on Sustainable Safety for non-motorized vehicles (Weijermars, Dijkstra, Doumen, Stipdonk, Twisk & Wegman, 2013). Recommendations are made in this vision for the design of streets within residential areas. On streets within residential areas, motorized vehicles should behave like guests, entering the domain of non-motorized road users. For cyclists, routes with a flow and with an exchange function should be distinguished. In the report is recommended to have separate infrastructure for cyclists on routes with a flow function in order to reduce the number of possible conflicts on the route. If there is not enough space available for separate infrastructure, other measures like speed reduction or wider streets are necessary to reduce the possible number of conflicts. On streets with an exchange function, the speed should be low to anticipate accurately on possible conflicts. In this report, it is proposed to apply a bicycle street-like design on other streets within a residential area to enforce cars to anticipate on the non-motorized users of the street and to emphasize the prominent position of non-motorized vehicles within residential areas. This report could put the current design of bicycle streets in a new position, since for main bicycle routes a new design with less exchange possibilities is proposed. The current bicycle street design should be suitable for streets within a residential area and a clear exchange function.

1.6 Problem and research objectives

Prior to the problem statement, a research has been carried out to investigate the current bicycle streets in the Netherlands. From this pre-research, a problem and research objective have been derived for this research. This research has been split up in a set of research questions.

1.6.1 Problem

There are no actual figures available about the number and length of bicycle streets in the Netherlands. However, a quick search shows that since the beginning of this century many bicycle streets have been realised. Only a few bicycle streets have been evaluated. Those evaluations mostly focus on the user's perceptions about the bicycle street and take sometimes the intensities of motorized and non-motorized vehicles on the bicycle street into account. However, objective traffic safety on bicycle streets has not been investigated yet.

At the same time, the number of crashes involving cyclists has increased over the last years. Especially the number of serious injuries in this crashes has increased. A new view on Sustainable Safety focussing on non-motorized vehicles is proposed by the SWOV, having a differentiation between bicycle routes with a flow function and an exchange function. Within residential areas the exchange function should be emphasized, the SWOV states that the current bicycle street design is suitable as base for this design. They also state that main bicycle routes with a flow function should be separated from streets with an exchange function. This statement requires a new design for bicycle streets in main bicycle routes (Weijermars et al., 2013).

So, the development of bicycle streets is still going on. In order to learn from the past and to improve the design for future applications, existing bicycle street designs should be evaluated.

These conclusions of the pre research have lead to the following definition of the problem:

The number of bicycle streets applied in the Netherlands over the last decade is estimated at a couple of hundred. However, little is known about the understanding of the existing designs and the driving behaviour related to those designs. Also little is known about whether the driving behaviour on bicycle streets is safe. Bicycle streets could play an important role in order to decrease the number of crashes with cyclists involved. To fulfil this role, more information is needed about the driving behaviour on the bicycle streets and probably an improved design could help to fulfil this role.

1.6.2 Research objective

Considering that bicycle streets could contribute to decline of the number of crashes with cyclists involved and that the current design is not optimal in terms of understanding, behaviour and traffic safety, the following research objective has been derived:

Analyse the two most used bicycle street designs in terms of understanding, behaviour and traffic safety in relationship with the design of these streets. Provide recommendations for future bicycle streets, based on the experiences with current bicycle streets.

1.6.3 Research questions

From the pre-research the following main research question has been derived that should be answered at the end of the study:

Is it possible to improve the design of bicycle streets in such way that the number of conflicts of cyclists with other cyclists or other users of the bicycle street could be reduced to improve the traffic safety on the bicycle street?

The main research question aims on determining whether the current applications in the Netherlands are traffic safe. Bicycle streets are applied in the Netherlands to provide attractive and safe routes for cyclists within residential areas (Andriesse & Ligtermoet, 2005).

As a guide for this research, the road design triangle is used. This triangle states that at a traffic safe road function, design and behaviour of the road users should be in accordance with each other. This research consists of three steps, each focussing on one of the three aspects of the triangle, given in Figure 5 (Janssen, 1974).

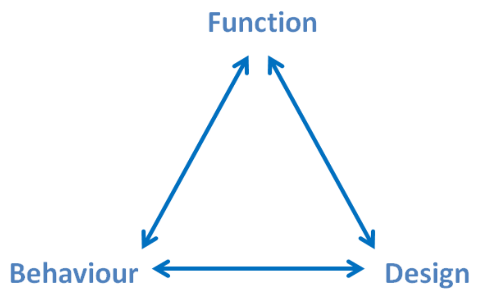


FIGURE 5: THE ROAD DESIGN TRIANGLE (JANSSEN, 1974) GIVES THE RELATIONS BETWEEN ROAD FUNCTION, ROAD DESIGN AND DRIVING BEHAVIOUR OF ROAD USERS ON THAT ROAD. THOSE THREE ELEMENTS ARE INTERRELATED AND INFLUENCE EACH OTHER. IT IS THEREFORE IMPORTANT TO PAY ATTENTION TO ALL ELEMENTS.

The first step will focus on the functions a bicycle street has in road and bicycle network. This step is split up in two parts. In the first part a theoretical framework will be developed for determining which functions could be assigned to a particular bicycle street. In order to create this theoretical framework, knowledge about bicycle networks and urban networks is necessary. Therefore the following sub research questions should be answered:

- *What is the position of the bicycle street in the urban network?*
- *What position does the bicycle street fulfil in a bicycle network?*
- *How could bicycle streets improve the traffic safety for cyclists?*

In the second part, the theoretical framework will be applied on the selection of bicycle streets that will be studied. To get a good insight in the functions each bicycle street has and how the traffic on the bicycle street is influenced by those functions, the following sub research questions should be answered:

- *Which functions could be assigned to the bicycle street based on a theoretical analysis?*
- *Are functions assigned to the bicycle street that could conflict and therewith influence the traffic safety?*
- *Are there other characteristics present on the bicycle street that may influence the traffic safety?*

In the second step, the behaviour on existing bicycle streets will be investigated. This part aims on determining the objective traffic safety on bicycle streets. Indicators that will be used are the speed of the different users and the intensities of motorized and non-motorized vehicles on the bicycle street. Also the driving behaviour of the different users will be investigated. Aspects of driving behaviour that will be investigated, are the place on the street and swerve and passing manoeuvres. After investigating the behaviour on the bicycle street, the following sub research question should be answered:

- *Does the observed behaviour meet the behaviour as intended by traffic engineers, assuming that those intentions are safe?*
- *Does other traffic give priority to the traffic on the bicycle street?*
- *Do parked cars along the bicycle street negatively affect the traffic safety on the bicycle street?*
- *Are the speed differences between the different traffic participants within safe limits?*
- *Is the speed choice of motorized vehicles related to the volume of cyclists on the bicycle street?*
- *Are the existing designs clear for the different user classes and is the driving behaviour of the different user classes therefore predictable?*

The results of the first two research steps will be tested to the infrastructure related principles of Sustainable Safety: functionality, homogeneity, predictability and forgivingness.

In the third step, the design of the bicycle street will be reviewed. Depending on the outcomes of the test to Sustainable Safety, the existing design of bicycle streets will be improved and translated into recommendations for bicycle streets. The sub research questions that should be answered after this part are:

- *Is it useful to adjust existing designs to improve the traffic safety on bicycle streets?*
- *Could the design of bicycle streets be adjusted in a way that the number of potential conflicts or the speed on conflict areas could be reduced?*
- *Which recommendations could be made in relation to the design of bicycle streets?*

The results of the sub research questions contribute to answer the main research question. The main research question could in theory be answered after the first two steps. However, the third step is also important for investigating the context of the design. A designer is often limited by spatial limitations and has to make choices in the design process. These choices are not always traffic driven, but also driven by for example urban planning aspects. In order to translate the more theoretical results of the first two steps in a more practical solution, the design step has been added to the research.

1.7 RESEARCH DESIGN

The goal of this research was to determine whether bicycle streets provide a safe solution for main bicycle routes through residential areas. To determine whether bicycle streets are safe, bicycle streets have been tested to the three infrastructure principles of Sustainable Safety: functionality, homogeneity and predictability and on the forgivingness of the environment of the street for road users.

The research design consists of three parts, based on the relations between function, behaviour and design. In the first part the method for investigating the functions of the bicycle street is captured, in the second part the method for investigating the behaviour on the bicycle street is explained and part three will deal with the design of bicycle streets.

The important functions of a bicycle street were investigated in part 1 by a literature study on the functions of streets, bicycle networks and the traffic safety of bicycle networks. This literature study has been carried out by a search via known literature search engines such as Science Direct and Google Scholar. Also the databases of the SWOV Dutch institute for road safety research and the Dutch bicycle knowledge platform Fietsberaad were consulted. Besides searches through the literature, also the so-called "snowball-method" was used. This method aims on finding recent literature and looking for relevant references within this literature.

The literature review has been presented in an annotated bibliography. In this style, the found references are organized in paragraph form presenting one subject per paragraph. The important functions and characteristics that have been distilled from the literature review were used to determine a theoretical framework. This framework formed the base of a function analysis of eight bicycle streets that were selected.

The functions and characteristics of those bicycle streets were analysed in the function analysis, still part of part 1: investigating the functions of the bicycle street. This analysis used the theoretical framework that has been derived from the literature study as a base. The important functions and design characteristics of bicycle streets are mapped. The goal of the function analysis was two sided.

On the one hand, the function analysis aimed on determining the different functions a bicycle street could have. Differences or similarities in the functions and characteristics of bicycle streets are interesting to investigate, since they could explain possible differences in design or behaviour. If there are many differences in the functions and characteristics of bicycle streets, the statement that bicycle streets are applied in different urban environments will be supported. If there are many similarities in the functions and characteristics of the bicycle street, one could state that the statement may not be true and that bicycle streets are often applied in urban environments with the same functions and characteristics. This could mean that bicycle streets are particularly suitable for those situations.

On the other hand, the function analysis could be used to explain differences in behaviour on the bicycle street. Differences in behaviour or usage between the studied bicycle streets might be explained by differences in functions and characteristics of bicycle streets. The outcomes of the function analysis help to connect possible differences in behaviour and usage to possible differences in functions and design characteristics. The statement that will be tested is: the behaviour on the bicycle street and usage of the bicycle street is related to the functions and characteristics of the street and its direct environment.

The behaviour and traffic composition of bicycle streets were studied in the second part. The behaviour and traffic composition have been studied by collecting data in the field and analyzing this data. The behaviour of traffic on the bicycle street has been tested to the intended behaviour as thought of by traffic engineers. This intended behaviour was determined by brainstorm sessions with traffic engineers at Grontmij and interviews with road authorities of the eight selected bicycle streets. Statements that were tested are related to this intended behaviour. The first statement in the second part states that the two-lane bicycle street design enforces cars more to stay behind the cyclists than the single-lane bicycle street design. The second statement states that cars do not give priority to the traffic on the bicycle street when crossing or entering the bicycle street. The third statement states that cars parked along the bicycle street are not a large problem for the traffic safety on the bicycle street. The fourth statement states that cars drive at the same speed as cyclists on bicycle streets. The fifth statement states that there should be more cyclists than cars on the bicycle street to enforce a low speed.

To accept or reject those statement, data was needed. This data has been collected by video recordings and observations at the bicycle street. Those recordings and observations were analysed to get a qualitative description of the behaviour on the bicycle street. The analysis of the data focussed on a couple of aspects. Those aspects are the place on the road of traffic participants, behaviour on intersections, parking cars along the bicycle street and speed behaviour of cars in the neighbourhood of cyclists.

For the fourth and fifth statements extra data was needed about the number of vehicles and the speed that is driven by those vehicles. Therefore road tube counters have been installed on the bicycle streets to generate data during a whole week. The dataset provided information about the type of vehicle, its speed, date, time and its direction. The differences in speed between cars and cyclists could be derived from this data as well as a possible correlation between the ratio cyclists/cars and the speed of cars.

Differences between the intended behaviour and the observed behaviour were explained by the means of human factors. Human factors is a research domain in which the interaction between humans and design is studied. A part of the research domain focuses on traffic psychology and the interaction between traffic participants and road design. This knowledge is useful to study the sixth statement in the second step: it is clear to each traffic participant that he or she is on a bicycle street where cyclists are the main users of the street. To investigate whether this statement could be rejected or accepted, pictures of the eight selected bicycle streets have been discussed with a colleague at Grontmij who has knowledge in the field of human factors and traffic psychology. The outcomes of this discussion were used to test the statement.

The first two steps were used to test bicycle streets to the infrastructure principles of Sustainable Safety: functionality, homogeneity and predictability. This was done by describing the findings per principle and comparing them with the safe intentions of those principles. The differences between the principles of Sustainable Safety and the real situation were used as a base for the third step. The statement tested in this phase is: the current design of bicycle streets meets the infrastructure principles of Sustainable Safety.

In the third step, the design of the selected bicycle streets was evaluated. The statement that was tested in this step is: the differences between the intended behaviour and the observed behaviour are related to the design of the bicycle street. Before general conclusions were drawn about those differences, the differences per bicycle street were studied and explained. Based on those conclusions, the design guidelines for bicycle streets, as present in the ASVV 2012 and the Design manual for bicycle traffic, were critically reviewed. If necessary, those guidelines have been updated based on the experiences with existing bicycle streets.

The whole process has been schematized in Figure 6. The related statement per step has been summed up in Table 1 below Figure 6.

FIGURE 6 SHOWS THE RESEARCH DESIGN BASED ON THE ELEMENTS FUNCTION, BEHAVIOUR AND DESIGN. IN A THEORETICAL STUDY, THE FUNCTIONS OF THE BICYCLE STREETS HAVE BEEN DETERMINED. EMPIRICAL RESEARCH WAS NEEDED TO STUDY THE DRIVING BEHAVIOUR ON THE BICYCLE STREET. THE OUTPUTS OF THOSE TWO RESEARCH STEPS ARE VISUALISED BY THE BLUE ARROWS AND ARE THE INPUT FOR A TEST TO FOUR OF THE FIVE SUSTAINABLE SAFETY PRINCIPLES. THE OUTCOMES OF THIS TEST WERE USED TO IMPROVE THE DESIGN OF BICYCLE STREETS.

TABLE 1 GIVES THE STATEMENTS THAT ARE TESTED PER RESEARCH STEP. THOSE STATEMENTS ARE BASED ON THE RESEARCH QUESTIONS THAT HAVE BEEN FORMULATED.

Step 1: Function analysis 1. Bicycle streets are applied in different urban environments 2. The behaviour on the bicycle street and usage of the bicycle street is related to the functions and design characteristics of the street and its direct environment
Step 2: Driving behaviour & traffic composition 1. The two-lane bicycle street design enforces cars more to stay behind the cyclists than the single-lane bicycle street design 2. Cars do not give priority to the traffic on the bicycle street when crossing or entering the bicycle street 3. Cars parked along the bicycle street are not a large problem for the traffic safety on the bicycle street 4. Cars drive at the same speed as cyclists on bicycle streets 5. There should be more cyclists than cars on the bicycle street to enforce a low speed 6. It is clear to each traffic participant that he or she is on a bicycle street where cyclists are the main users of the street
Testing to Sustainable Safety 1. The current design of bicycle streets meets the infrastructure principles of Sustainable Safety
Step 3: Design improvement 1. Differences between the intended behaviour and the observed behaviour are related to the design of the bicycle street

The selection of bicycle streets has been made based on both practical and theoretical arguments. Practical arguments to choose a particular bicycle street were travel distance from my home in Delft to a particular bicycle street and available information about the bicycle streets. Theoretical arguments to choose a particular bicycle street were information about the ratio cars/bicycles on a bicycle street or information about the functions of the bicycle street in the network. Another selection criterion was that all the bicycle streets should have a recognizable and characteristic bicycle street design, so or a two-lane bicycle street or a single-lane bicycle street. Another criterion was to select only one bicycle street per municipality in order to have a variation in designs and driving behaviour. The last selection criterion was to have an equal distribution between the two designs that will be studied. This last criterion aims on an equal representation of both designs in this research, but makes it also possible to compare both designs with each other. The eight selected bicycle streets are presented in Table 2.

TABLE 2: FOUR TWO-LANE BICYCLE STREETS AND FOUR SINGLE-LANE BICYCLE STREETS ARE SELECTED TO MAKE A COMPARISON BETWEEN THE DIFFERENT DESIGN VARIANTS

City	Street	Design variant
Alkmaar	Frieseweg	Two-lane bicycle street
Castricum	Dorpsstraat	Two-lane bicycle street
Delft	Ezelsveldlaan	Two-lane bicycle street
Zoetermeer	Zegwaartseweg	Two-lane bicycle street
Haarlem	Venkelstraat	Single-lane bicycle street
Houten	Prinses Ireneweg	Single-lane bicycle street
Oss	Asterstraat	Single-lane bicycle street
Zwolle	Vondelkade	Single-lane bicycle street

Studying four bicycle streets per design variant makes it possible to generalize conclusions per design variant. Those generalized conclusions can indicate differences between both variants and make it possible to compare the design variants. The variants that will be investigated are the most used designs in the Netherlands. The choice for four bicycle streets per design variant makes it further possible to compare bicycle streets with the same design and to determine success and fail factors within the design.

1.8 LIMITATIONS

Considering the available time and resources, this research has limitations. The aspects that are not taken into account are given in this chapter, bundled per theme.

Geographically

Only a selection of bicycle streets will be studied. The selected bicycle streets are mostly located in the Randstad in order to limit the travel time to and from the measurement locations.

Furthermore, only bicycle streets within built-up areas are considered. Bicycle streets outside the built-up area have often a different design and different functions than bicycle streets within built-up areas. The results of this study are therefore not one-on-one applicable on bicycle streets outside the built-up area.

In the function analysis the whole main bicycle route where the bicycle street is a part of, will be considered. The practical aspect will only focus on a part of the street, mostly between two intersections.

In some situations, a bicycle street is implemented on a street that is not part of a main bicycle route. The use and functions of these streets differ from bicycle streets in main bicycle routes. Therefore, only bicycle streets that are a part of main bicycle routes will be considered. A parallel road of a distributor road has sometimes a bicycle street design instead of a bicycle path. In this study, only bicycle streets through residential areas are considered, so no parallel roads.

Design variants

Only single-lane bicycle streets or two-lane bicycle streets are studied in this research, because those designs are developed for bicycle streets. Those designs are also the most present in literature about bicycle streets.

The selected bicycle streets are all bidirectional streets for all modes. Bicycle streets with cars in one direction and bicycles in two directions are not selected, while they are applied a lot. This choice has been made to make a fair comparison between two-lane bicycle streets and single-lane bicycle streets. Two-lane bicycle streets are almost always bidirectional, while this for single-lane bicycle streets differs from street to street.

Design aspects

The recommendations for new designs of the bicycle street will focus on the traffic engineering aspects of the bicycle street. Other aspects such as green facilities, road furniture, lightning and so on, will not be taken into account.

Functions

Besides the traffic functions, also the urban functions of the street will be mentioned. However, since this research focuses on the traffic safety of bicycle streets, those functions will not be deepened out that much. This research will therefore not capture the full picture as it comes to the urban functions of the bicycle street.

Measurement time & location

The video recordings will only take place at one moment and one location and will not be repeated at other times, days or locations.

Circumstances

The influence of different circumstances on bicycle streets are not taken into account. Different circumstances could for example be darkness or snow. However, the weather conditions at the moment of measurements will be registered.

Safety

The subjective traffic safety of bicycle streets will not be studied, this is already done in most existing evaluations. This means that no surveys will be carried out to study the user's perception of the safety of the bicycle street.

The objective traffic safety will not be studied using the BRON (Basis Registratie Ongevallen Nederland, registration of crashes in the Netherlands) database. The registration of crashes in this database is decreasing since 2009, so in order to have a good view on the accidents that occur on bicycle streets, older data is necessary. However, most of the selected bicycle streets are not that old that there will be enough data available.

2 Bicycle streets in the road and bicycle network

Bicycle streets are part of the urban and bicycle network. The effectiveness of the application of a bicycle street depends for an important part on the position of the bicycle street in the network. This position determines the functions a bicycle street has to be designed for. Some functions are general for almost every bicycle street, other functions are related to the position of the bicycle street. Different functions will have different design requirements and conflicting functions could have conflicting design requirements. The functions of a bicycle street could also influence the use of the bicycle street and therewith the traffic safety of the bicycle street.

A small literature study has been carried out, studying the functions of bicycle streets in the urban and bicycle networks. Also the traffic safety of bicycle networks and the possible contribution of bicycle streets to safer bicycle networks have been studied. This study focuses mainly on the traffic planning related aspects of bicycle streets, but also urban planning aspects were part of the research.

The structure of this chapter is as follows: first, the road network in general is studied, focussing on the different functions within an urban network. Second, the general structure of bicycle networks and traffic safety issues of bicycle networks are studied. Last, the functions of bicycle streets and the possible conflicts between those functions are considered.

2.1 Road network

The Netherlands have a long tradition of urban and spatial planning policies. Especially since the Second World War, the Netherlands have passed through a period of establishing many spatial and urban policies, some more successful than others. To spare the green areas as much as possible, building areas have been concentrated as much as possible. Due to this policy, the Netherlands have one of the highest building densities within built-up areas (Alpkokin, 2012). This makes it hard and costly to implement future adjustments within the urban network.

Historical urban networks often have a radial network, connecting the gate of the city with the central market place (Bach, Hal, Jong & Jong, 2006). Later in history, the grid structure was preferred by urban planners, as it provides rectangular allotments and creates the most efficient land use. After the Second World War, new plans such as a tree structure came up, mostly trying to achieve a modal shift from car to public transport, walking and cycling. However, the general urban structure has more and more been designed from a car user's perspective instead of a cyclist's perspective. This has resulted in networks with different hierarchies, providing a higher capacity and speed at a higher network level. Detours caused by this network structure are compensated by the higher speed and capacity, resulting in lower travel times. Cycling and public transport networks have often been fit into those networks, not profiting from these higher levels as detours mainly result in higher travel times.

Within an urban area, roads have different functions. Roughly, two main functions could be determined: a traffic and a residential function. An example of public space with a residential function is a living street. For public space with a traffic function, a division in three functions is made. Roads could have an access function, a distribution function or a flow function (Janssen, 1997). Based on the functionality of roads, a road hierarchy has been setup in the Sustainable Safety program, distinguishing through-flow roads for the flow function, access roads for the access function and distributor roads for roads with a distribution function (Wegman & Aarts, 2006).

The functionality principle within Sustainable Safety aims on one exclusive function for each road (SWOV, 2010a). For most roads in the Netherlands this means that they are classified as access roads, having a residential function. In order to improve the traffic safety, as large as possible traffic-calmed residential areas containing only access roads have been created. However, those residential areas could not become too large, since the detours for motorized traffic would become too large (Dijkstra, 2003).

Urban Planners have criticized the radical road categorizing as proposed by Sustainable Safety, since the vision focuses too much on traffic flows and too less on urban qualities. So parallel to the development of Sustainable Safety urban planners looked for alternative ways of improving traffic safety, without radical road categorizing. They introduced urban qualities like liveliness, significance, functional mix and spatial qualities and combined them with the aspects of traffic flow and traffic safety (Bach et al., 2006). These ideas have led to several new visions trying to introduce urban qualities in a safe road design.

The shared space concept (Monderman, 2004) is one of the visions trying to combine urban qualities with an improvement in traffic safety. By using natural and historical elements in the road design, reducing the number of traffic signs and preferably providing basic traffic facilities only, the speed is lowered in a natural way. People are forced to communicate with other users of the space to anticipate on potential conflicts (Hamilton-Baillie, 2008). Since communication between road users is one of the most important steps in improving traffic safety, the shared space seems to be actually safe. However, the concept is only useful for application on streets with a pure residential function. If a street has a traffic function for one or more user classes on the street, the street cannot be turned into a shared space. A bicycle street has a residential function, but facilitates also a traffic function for cyclists. This mix is not possible in a shared space area.

Traffic safety and urban planning are connected and cooperation between urban planners and traffic engineers is therefore necessary to create an attractive and safe public space. It is possible to create sustainable safe attractive public and traffic spaces, if the correct choices are made (Hal, Temme & Heijden, 2002). The function of a road, for motorized vehicles and cyclists, but also the environment surrounding the road determines the design of a road and the safe and credible speed on a road. This interrelation is given in Figure 7.

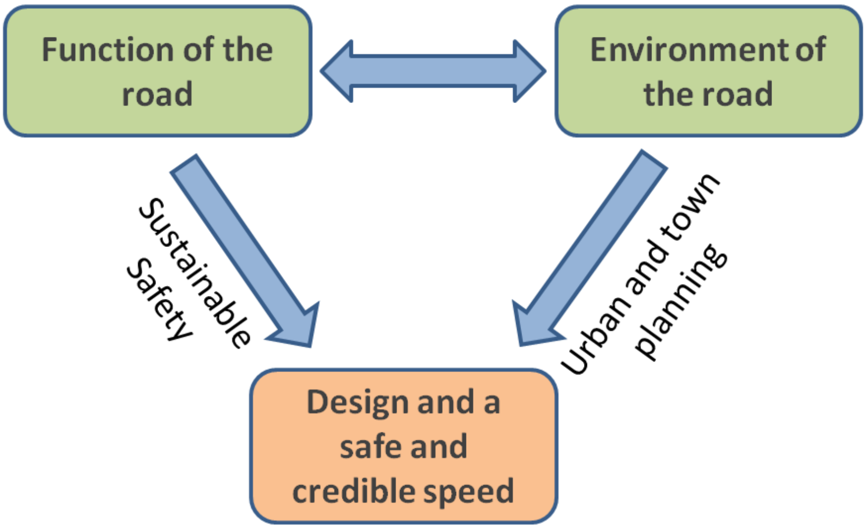


FIGURE 7 SHOWS THAT THE FUNCTION OF THE ROAD AND THE ENVIRONMENT OF THE ROAD ARE INTERRELATED. BOTH ELEMENTS DETERMINE THE DESIGN OF A STREET, ONE FROM A SUSTAINABLE SAFETY POINT OF VIEW, THE OTHER FROM AN URBAN AND TOWN PLANNING POINT OF VIEW. WHETHER THE SPEED LIMIT IS CREDIBLE AND THE DRIVEN SPEEDS ARE SAFE, DEPENDS ON THE TOTAL DESIGN OF THE STREET (HAL, TEMME & HEIJDEN, 2002).

There is a strong interaction between the function and the environment of the road. On one hand, the environment of a road determines which function a road should have, while on the other hand the function of a road determines the direct environment of the road. The environment of the road is the working field of urban and town planners, while the function classification and design belongs to the working field of traffic engineers. The function of a road, together with the principles of Sustainable Safety determine the technical design of the road. The environment of the road is designed by urban planners using principles for urban planning and urban quality. Together, they determine the complete design of a road and its environment.

Studies have shown that the traffic safety in a street depends on the urban characteristics of a street (Dijkstra, 1988). It has been shown that the speed choice depends to a small extent on urban characteristics such as the dimensions of the horizontal plane, situation and size of the real estate along the street and the cross-sectional profile of the carriageway. Discontinuities affect the speed only for a short distance.

Important in the design of streets within urban networks is to have a clear vision about the different functions of a street. Residential and traffic functions are often conflicting. An easy way to prevent conflicts from happening, is to separate those functions within a network or even within a street. This does not always affect the urban qualities in a positive way. Routes with more liveliness along the route are more attractive to non-motorized traffic than routes without liveliness. At the same time, urban traffic is an important source of liveliness within a city. Traffic designers and urban planners have different views on the design of public space for motorized traffic within the urban space. However, they both are responsible for the urban design of a street and the driven speed related to this design.

2.2 BICYCLE NETWORKS

A bicycle network consists of interconnected cycle paths, cycle lanes and other roads which are designed to serve the cyclist's needs. The provision of a direct and safe connection from origin to destination determines the functionality of the network. Cyclists have to understand the network easily in order to create a mental map of the areas. This helps in orientating within the comprehensive network of cycling routes (Eltis, 2012).

In the route choice of cyclists, direct routes with short journey times are the most important determining factor, followed by infrastructure type, number of junctions along the route, traffic speed and cyclists volumes (Caulfield, Brick & McCarthy, 2012). The cyclist's preference for short and direct routes influences the structure of main bicycle routes. A short study considering the main bicycle routes of a couple of Dutch municipalities shows radial networks as structure for main bicycle routes, with the city centre or main railway station as the centre of the network (Andriesse & Ligtermoet, 2005; Ridder & Brussel, 2006; Goossens, 2008; Fietsersbond Utrecht, 2010). A radial network offers shortcuts and direct connections and therefore saves time.

The implementation of Sustainable Safety has led to larger traffic-calmed residential areas in the Netherlands. In 1998, before the implementation of Sustainable Safety, 15 percent of the residential streets in the Netherlands had a speed limit of 30 km/h, while in 2008, 75 percent of the residential streets had a speed limit of 30 km/h (SWOV, 2010b). Within residential areas, the amount of motorized traffic is limited since traffic should have its origin or destination within the area. Through-going motorized traffic could be averted from urban areas by making through-going roads impossible or unattractive. However, these measures may not limit the accessibility for pedestrians and cyclists to the area. Extra shortcuts and priority regulations could help to prevent delay along bicycle routes (SWOV, 2010b).

Bicycle use depends on the availability of direct, continuous and safe routes without missing links (Bach et al., 2006). In CROW publication 230 "Ontwerpwijzer Fietsverkeer" (CROW, 2007) five quality requirements for bicycle routes are mentioned. These requirements, continuity, directness, safety, comfort and attractiveness, help to increase the quality of a bicycle route and to attract more cyclists.

Within a city, a couple of main bicycle routes can be determined. These main bicycle routes are through-going bicycle routes, have a length of at least one kilometre, connect important functions, achieve a certain bundling on the route and are used by many cyclists (Andriesse & Ligtermoet, 2005). Those main bicycle routes are often traced through residential areas.

For main bicycle routes within residential areas, Andriesse and Ligtermoet (2005) come up with four possible embodiments:

1. A solo bicycle path, often hard to apply in existing urban areas
2. A bicycle track along an access road with low speeds and volumes
3. An access road with a mixed profile, low speeds and low car intensities
4. An access road with too high car intensities and speeds, does actually not fit into Sustainable Safety

Possibility #3 meets the functional requirements for a bicycle street: mixed profile, low car intensity and low speeds.

2.3 Traffic safety of bicycle networks

Cyclists are very vulnerable in traffic, due to a lack of protection and mass in comparison with other traffic (Wegman & Aarts, 2006). To reduce the impact of a crash on cyclists, cyclists are only mixed with other traffic at low speed. Sometimes, high volumes of traffic flow require a higher speed for cars. In this case, cyclists are separated from other traffic to homogenize the speed and mass, reducing the impact of conflicts. Within urban areas, it is recommended to mix cyclists on access roads with a speed of 30 km/h and separate on distributor roads with a speed of 50 km/h. At through-roads within urban areas with a speed of 70 km/h, cyclists have to be separated anyhow (CROW, 2012).

These ideas have been implemented over the last fifteen years in follow up to the Sustainable Safety program as proposed by the SWOV Institute for Road Safety Research (SWOV, 2010c). In general, there seems to be a correlation between the implementation of Sustainable Safety on the Dutch roads and the strong decrease in the number of crashes, injuries and deaths (Wegman, Dijkstra, Schermers & Van Vliet, 2005). However, over the last years a growth in the number of crashes, injuries and deaths among cyclists could be distinguished (Wijlhuizen et al., 2012). New impulses are needed, focussing on particular solutions per target group (Ministerie van Infrastructuur en Milieu, 2012). One of the solutions is gathering and sharing more knowledge about the safety of bicycle amenities.

In order to reduce the number of serious injuries in traffic, the SWOV proposes an improvement of Sustainable Safety (Weijermars et al., 2013). Figure 8 shows that the number of serious injuries in traffic ('aantal ernstig verkeersgewonden') has grown over the last years in case of crashes without motorized vehicles involved (blue line), while in case of crashes with motorized vehicles involved (green line), the trend is decreasing.

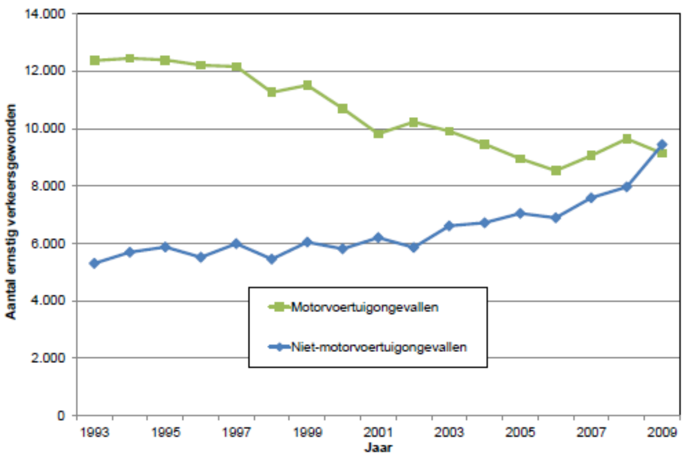


FIGURE 8: THE NUMBER OF SERIOUS INJURIES IN MOTORIZED AND NON-MOTORIZED CRASHES IN THE LAST SIXTEEN YEARS (WEIJERMARS ET AL., 2013). WHILE THE NUMBER OF CRASHES WITH MOTORIZED VEHICLES INVOLVED DECREASED OVER THE YEARS, AN INCREASEMENT IN CRASHES WITH ONLY NON-MOTORIZED VEHICLES INVOLVED CAN BE OBSERVED IN THE LAST FIVE YEARS.

In 98% of the crashes with only non-motorized vehicles involved, the serious injured victims are cyclists. In 92% of those crashes, no other traffic than the victim was involved (Weijermars et al., 2013). One of the conclusions Weijermars et al. (2013) draw, is that the traffic safety for cyclists can be improved by adjusting the infrastructure within residential areas to the characteristics of cyclists. These conclusions are selected because of their relation with the bicycle street. Weijermars et al. (2013) recommend to use a 'bicycle street-like' design for streets within residential areas. Those designs should enforce motorized vehicles to anticipate on cyclists on the street. On main bicycle routes, separation between the functions reside and flow should be achieved. These recommendations are contradictory with the current application and design of bicycle streets.

On the other hand, main bicycle routes should be planned through residential areas, combining flow and reside functions, as those areas are large and the detour for cyclists for cycling along the distributor roads will often become too large (Weijermars et al., 2013). Besides the detours caused by cycling along the distributor roads, distributor roads have a higher fatality risk, since about 75% of the fatal cycle crashes took place at distributor roads (SWOV, 2010d). Most of the crashes between cyclists and motorized vehicles within the urban area occur at unsignalized priority-intersections of distributor roads (Schepers, Kroeze, Sweers & Wüst, 2011).

In Berkeley, California USA, bicycle boulevards have been designed parallel to the busy arterial roads to provide cyclists a healthier, more attractive and especially safer alternative for cycling along the busy arterial roads. Those bicycle boulevards have low traffic volumes, a low intensity of heavy traffic and low driving speeds. A small study evaluating the traffic safety of those bicycle boulevards shows that the parallel, traffic-calmed bicycle boulevards are much safer than the busy arterials (Minikel, 2012). Although there are big differences between the road design in the USA and the Netherlands, especially in the design and availability of bicycle amenities, some analogies could be seen. The characteristics of bicycle boulevards are comparable with those of bicycle streets. In the Netherlands, it could also be more attractive to invest in safer parallel routes than in bicycle amenities along distributor road.

In the Netherlands, the bicycle use is growing (Heinen, 2011). A reduction in the crash risk for cyclists will not necessary lead to a decrease in the number of crashes, because the exposure to the crash risk has grown. If the kilometres travelled by bike are increasing, a reduction of the number of crashes could only be obtained by reducing the risk (Wegman, Zhang & Dijkstra, 2012). By seducing cyclists to take an alternative, safer route, the number of crashes with cyclists could be reduced. These routes could be improved by limiting the car use of the routes, bicycle street designs and grade separated intersections with distributor roads. In this way, the bicycle network could be unbundled from the distributor road network (Schepers, Heinen, Methorst & Wegman, 2013). To unbundle the bicycle network from the road distributor network, bicycle streets should not only be applied on the several main bicycle routes within a city. The network should also be extended by tangential links, providing attractive alternatives for the routes along distributor roads.

So, within bicycle networks a hierarchy of bicycle routes could be distinguished, containing a couple of main bicycle routes with a radial structure, local bicycle routes connecting origins and destinations with the main bicycle routes and less important bicycle routes. From a cost/benefit perspective it is attractive to invest in the traffic safety of main bicycle routes and to bundle bicycle traffic at those main bicycle routes. From a traffic safety perspective it is attractive to unbundle those main bicycle routes from the distributor road network. By providing attractive bicycle routes unbundled from the distributor roads, the traffic safety for cyclists could be improved.

2.4 Functions of bicycle streets

Within an urban area, two main functions for streets could be distinguished: a residential function and a traffic function (Bach et al., 2006). Those functions could both be distinguished from a motorized vehicle perspective as a non-motorized vehicle perspective. Wegman & Aarts (2006) distinguish three functions for the traffic function and connect these to three road categories. Bicycle streets are always categorized as access roads (Andriesse & Ligtermoet, 2005).

However, a bicycle street only has this access function for residents or visitors of buildings along the street. For large volumes of cyclists, the bicycle street is part of a main bicycle route and for those users the street should have a flow function. So a bicycle street has conflicting traffic functions since it combines an access function for all kinds of traffic with a flow function for bicycle traffic. Both functions have other design requirements for the bicycle street and could also cause conflicts in behaviour of traffic participants.

A bicycle street is in the first place a residential street. A residential street provides access to the houses along the street, but besides that it is also a meeting place for residents, a play area for children or a visual setting (Eran, 1995). One could further think of other functions, such as a street part of a shopping area or part of a recreational walking or cycling route. Furthermore, a residential street provides often parking spaces along the street for residents and visitors.

Extreme high bicycle volumes could reduce the liveability of a residential street. The number of mopeds on the bicycle street is more dangerous for the liveability of the street, since for them the bicycle street is often the most attractive route. Mopeds have a higher speed than most cyclists, produce more noise, are less manoeuvrable and have a higher mass than cyclists. They could therefore be a threat for the liveability of the street as they are hard to influence by the design or traffic measures. However, less is known about the threat of mopeds on bicycle streets.

A residential street is a place of social interacting, having many different types of users with different masses, purposes, speeds and directions. The behaviour of those different types of users is not always predictable for other users of the residential street. In order to react on possible conflicts in a proper way, speeds on the residential street should be low and there should be enough space available to avoid conflicts.

A road with a traffic function should have homogeneous traffic: as small as possible differences in mass, speed and directions between users of the same traffic space (SWOV, 2010a). The design of roads with a traffic function should aim on separating users with large differences in mass, speed and direction.

Bicycle streets are residential streets with a traffic function for cyclists. The combination of through-going cyclists with probably a relatively high speed, and residential traffic with a low speed could cause conflicts and reduces the traffic safety. Traffic engineers have created the profile in such way that those conflicts could be avoided safely. However, in practice this mix of traffic could be unsafe because road users do not always behave like designers intend. So could the speed of the cars be too high or could road users react on each other in another way as intend. The bicycle street could also be unsafe due to a wrong combination of functions that is designated to the bicycle street. So a bicycle street should only accommodate local motorized traffic with an origin or destination directly at the bicycle street. If also other motorized traffic has to use the bicycle street or uses the bicycle street because it is the most attractive route for them, the intensities and speeds of motorized traffic could become too high and cause traffic unsafety.

In summary, a designer should have a good overview of the functions of the street when designing a bicycle street. Attention should be paid to the position of the street in the network of motorized traffic and the mix between motorized traffic and cyclists. Also attention should be paid to the urban qualities of the street as it is also a residential street. The through-going bicycle traffic will cause liveliness in the street, but could also reduce the liveability.

2.5 THEORETICAL FRAMEWORK FOR FUNCTION ANALYSIS

This literature study has been used to derive a theoretical framework for the function analysis of bicycle streets. The theoretical framework will help to collect all the relevant functions and characteristics of the bicycle street. Insight in the relevant functions is important for the evaluation of the bicycle street since the functions could influence the usage of the bicycle street and the behaviour of the users.

This theoretical framework provides a structure for collecting the different functions. The structure contains a set of main functions and presents the analysis of those main functions in a logical order. In the first step is the flow function determined at the scale of the whole main bicycle route. Then is zoomed on the environment around the bicycle street to determine the urban function of the bicycle street. The last step zooms further on the bicycle street itself to determine the access function of the street.

Due to the facilitation of large volumes of cyclists, bicycle streets contain a flow function besides their access function. This first step focuses on the flow function of bicycle streets. To get a good insight in the flow function it is necessary to start with mapping the main bicycle route where the bicycle street is part of. Possible origins and destinations for cyclists along the route are studied. Also the applied road designs on other parts of the route are investigated since the attractiveness of the main bicycle route could be influenced by worse designs of other parts of the main bicycle route than just the bicycle street that is studied.

After the bicycle route has been mapped, the urban functions are investigated. In this research step, the activities along the bicycle street are studied. The type and location of buildings along the route, such as residential, offices or shopping and the users related to these buildings are inventoried. Furthermore, functions related to those activities, for example parking, and the facilitation of those functions in the current design are subject of study. Also urban characteristics such as the dimensions of the horizontal plane, the type of buildings and the building densities along the bicycle street are studied since the urban environment plays an important role.

In the third step, the access function of the bicycle street is studied. The place of the bicycle street within the local network is investigated, determining whether the bicycle street is part of a through-going route or ends in a cul-de-sac for motorized traffic. Also the attractiveness of the route for motorized traffic is studied. This is done by investigating whether the bicycle street is part of the shortest or fastest route for traffic without their origin or destination directly along the bicycle street or surrounding streets. The attractiveness of the route could be reduced by introducing one-way streets and loops for motorized traffic. These traffic measurements are also investigated since it is important to have only local motorized traffic on the bicycle street and to certainly prevent through-going motorized traffic. There could also activities be located along the bicycle route that generate more car traffic than general housing such as supermarkets or other shops. These activities may also attract trucks for replenishment of the shops. The last subject that is investigated is whether public transport is using the bicycle route. Busses using the bicycle street could affect the traffic safety due to the difference in mass. If busses are using the bicycle street, the route is often also through going for other traffic than cyclists, at least for a part.

These three steps form a theoretical framework for analyzing the functions of bicycle streets. This framework is schematized in Figure 9.

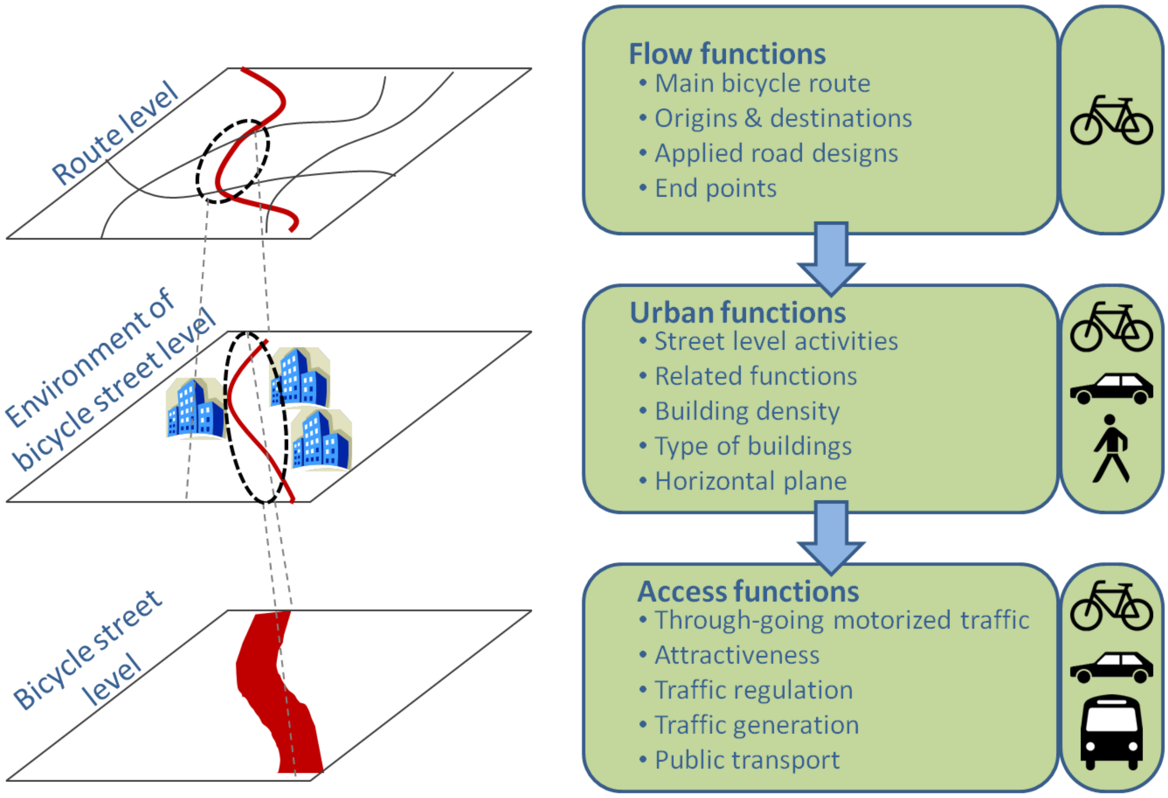


FIGURE 9 SHOWS THE THEORETICAL FRAMEWORK FOR ANALYZING THE FUNCTIONS OF BICYCLE STREETS. ON A ROUTE LEVEL, THE FLOW FUNCTION FOR CYCLISTS ON THE BICYCLE STREET IS INVESTIGATED. THEN IS ZOOMED ON THE ENVIRONMENT OF THE BICYCLE STREET TO DETERMINE THE URBAN FUNCTIONS OF THE BICYCLE STREET. IN THE THIRD STEP IS ZOOMED ON THE ACCESS FUNCTIONS OF THE BICYCLE STREET ON A BICYCLE STREET LEVEL.

3 FUNCTION ANALYSIS

The theoretical framework derived in the previous chapter has been used to analyse the important characteristics of each bicycle street. The analysis has been executed at different levels, starting with the complete main bicycle route and zooming in on the urban and access functions of the bicycle street.

Each street has been analysed and described. This analysis can be found in appendix A. The results of this analysis are divided in three steps: flow, urban and access functions. In each step, the functions of the bicycle street have been studied on a different scale, starting with a study on route level, followed by the environment of the bicycle street in step two and focussing further on the functions on a bicycle street level in step three.

Several aspects have been studied per step. The results of the analyses are presented in each step, giving the outcomes per bicycle street and per aspect in a table.

3.1 FLOW FUNCTIONS

In this step, the functions of a bicycle street have been analysed on a route level to determine the flow function a bicycle street has in a bicycle network. Four aspects have been studied in this analysis step. The studied bicycle streets are part of a main bicycle route.

In the first aspect, this main bicycle route was analysed. The position in the network has been described by determining whether the main bicycle route forms a radial or a tangential connection in the bicycle network. Further has the total length of the bicycle route been determined.

The second aspect that has been studied covers the origins and destinations of cyclists along the main bicycle route. The most important origins and destinations along all the studied bicycle routes are houses in the residential areas that are connected by the bicycle route. The study focussed on public attracting buildings or areas, such as schools, hospitals or shopping centres. Not only the number of public attracting buildings, but also the distance to the bicycle route and the spread of those buildings along the route were studied. Those aspects are judged in a qualitative way, assuming that many public attracting buildings, spread along the main bicycle route on a short distance of the route do positively contribute to the performance of the bicycle route, while less public attracting buildings at a larger distance at the end points contribute negatively.

The third aspect focused on the applied road designs on the main bicycle route. On the one hand, the bicycle facilities were studied and judged in a qualitative way. It is assumed that a bicycle path or a bicycle street does positively contribute to the main bicycle route, while bicycle lanes or a street without bicycle facilities will negatively contribute. The most applied design in kilometres were judged. On the other hand, the variation in designs applied on the bicycle route has been judged in a qualitative way. It was assumed that a large variation in designs applied negatively contributes to the performance of the bicycle route, while a small variation will positively contribute to the performance. Further was the priority regulation on intersections between the bicycle route and distributor roads investigated. If the bicycle route has priority on most of these intersections, this is considered as a positive contribution, while if the distributor road has priority in most cases, this is considered as a negative contribution.

The fourth and last aspect that has been studied, dealt with the end points of the bicycle street and main bicycle route. About the end points of bicycle streets could be concluded that the bicycle street forms a connection between other bicycle facilities. So at the end points of the bicycle streets, the main bicycle route continues via a bicycle path or lanes. The main bicycle routes do often not have a clear end points. Bicycle traffic is often bundled on the bicycle route and only cycles on a part of the total route. This makes it hard to identify the end points of the bicycle route and the way they are designed. This aspect has therefore not been included in Table 3.

TABLE 3: THE STUDIED FLOW FUNCTIONS ARE JUDGED PER ANALYSIS ASPECT. THE TABLE SHOWS THAT THE STUDIED BICYCLE STREETS DIFFER STRONGLY FROM EACH OTHER CONSIDERING THE DIFFERENT ASPECTS. EVEN WITHIN ONE TYPE OF BICYCLE STREETS NO SIMILARITIES COULD BE FOUND.

		Two-lane bicycle streets				Single-lane bicycle streets			
		Alkmaar	Castricum	Delft	Zoetermeer	Haarlem	Houten	Oss	Zwolle
Main bicycle route	Position	Radial	Radial	Tangential	Tangential	Radial	Radial	Radial	Radial
	Length	5500 m	1500 m	4500 m	4100 m	3100 m	2600 m	2600 m	3400 m
Origins & Destinations	Presence	-	0	++	0	-	+	+	+
	Distance	-	++	+	--	0	+	++	+
	Spread	-	+	++	++	-	-	++	+
Road designs	Designs	++	0	+	0	+	+	+	+
	Variation	++	++	--	-	+	++	++	+
	Length bicycle street	850 m	900 m	240 m	2300 m	250 m	500 m	600 m	700 m
	Priority	++	0	0	+	0	++	-	+

Table 3 shows that the studied aspects differ strongly per bicycle street. Even within one type of bicycle streets, no similarities could be found. Interesting outcomes are the great lengths of the different main bicycle routes and the variation in lengths of the different bicycle streets.

3.2 Urban functions

The second step zooms in on the direct environment of the bicycle street to the determine the urban functions of the buildings along the bicycle street. In this step, five aspects have been studied to determine the functions of the environment and how the environment could influence the traffic on the bicycle street.

The first aspect maps the activities in the buildings along the bicycle street at street level. Options that have been found are housing, offices, shops and catering. The street level activities influence the profile and character of the bicycle street, but influence also the traffic patterns and driving behaviour on the bicycle street.

Related functions to those street level activities are studied in aspect two. Related functions that were analysed are parking along the street, stopping and turning vehicles and trucks supplying offices or shops along the bicycle street. Those related functions could influence the traffic safety on the bicycle street. Trucks supplying offices or shops along the street could for example block a part of the carriageway and form an obstacle for cyclists.

The building density along the street is the third aspect that has been studied. The building density has been described in a qualitative way defining the building density as high, medium or low. The building density is important since it determines the profile of the bicycle street. The building density further influences the traffic generation and is also important for the feeling of human scale.

Besides the building density, the profile is also influenced by the type of buildings. The type of buildings is qualified by the age of the buildings along the bicycle streets. Each decade has its own building style and provides therefore another character to the street. The character could influence the experience road users have on the street and therefore influence the driving behaviour.

In the fifth and last aspect, the horizontal plane of the bicycle street has been measured. With the horizontal plane is meant the distance from house front to house front. This distance varies along the street. The given value is therefore an average value, based on several measurements on different locations. These measurements have been done in Google Earth. The horizontal plane indicates whether the profile of the street is narrow or wide. The wider the profile, the faster vehicles will drive.

In Table 4, the results per aspect are shown.

TABLE 4: THE URBAN FUNCTIONS AND CHARACTERISTICS OF THE STUDIED EIGHT BICYCLE STREETS. THERE IS A LARGE VARIATION IN THE URBAN CHARACTERISTICS AMONG THE STUDIED BICYCLE STREETS. INTERESTING IS THAT THE EXTREME VALUES SUCH AS THE HIGHEST AND LOWEST BUILDING DENSITY AND THE SMALLEST AND LARGEST HORIZONTAL PLANE CAN BE FOUND AT THE TWO-LANE BICYCLE STREETS. FURTHER HAVE THE SINGLE-LANE BICYCLE STREETS A CLEAR HOUSING FUNCTION, WHILE AT TWO-LANE BICYCLE STREETS A MIX OF FUNCTIONS IS FOUND.

	Two-lane bicycle streets				Single-lane bicycle streets			
	Alkmaar	Castricum	Delft	Zoetermeer	Haarlem	Houten	Oss	Zwolle
Street level activities	Housing; some firms	Housing; shops; cafes; restaurants; offices	Housing; shops; offices	Housing;some firms	Housing	Housing	Housing	Housing
Related functions	Parking; supplying trucks	Parking; supplying trucks	Parking; supplying trucks	Parking; supplying trucks	Parking	Parking	Parking	Parking
Building density	Medium	Medium	High	Very low	Medium	Low	Medium	Low
Type of buildings	1930s building style; new buildings	Mix of styles	1930s building style; new buildings	Mix of styles	1980s buildings	1970s buildings	1930s buildings	1930s buildings
Horizontal plane	30 m	16 m	12 m	40 m	15 m	20 m	18 m	18 m

Table 4 shows that at single-lane bicycle streets, the urban characteristics are comparable. All the studied single-lane bicycle streets have only a housing function, are typical residential streets and have comparable horizontal planes. At the two-lane bicycle streets, there is a large variation in functions, building densities and horizontal planes among the different studied bicycle streets. All the two-lane bicycle streets contain truck traffic related functions.

3.3 ACCESS FUNCTIONS

In the last step is zoomed in on the bicycle street and the traffic on the bicycle street. Five aspects have been used to analyse the position of the bicycle street in the car network to predict the use of the bicycle streets by cars. In an ideal situation, the bicycle street has only an access function for cars and cars have their origin or destination directly along the bicycle street.

The first aspect studied the through-going motorized traffic on the bicycle street. A route analysis has been used to determine whether the bicycle street provides a shorter or more direct route for motorized traffic. If this is the case, it could be expected that a part of the motorized traffic on the bicycle street is through-going traffic that should not be there. The level of through-going motorized traffic that is expected on the bicycle street is presented in a qualitative way. If through-going motorized traffic is not possible, a positive appreciation is given. If through-going motorized traffic is expected on the bicycle street, a negative appreciation is given.

In the second aspect, the attractiveness of the bicycle street has been studied. When there are two comparable routes available, the bicycle street could become more attractive than the other route since traffic on the bicycle street has priority. If a bicycle street provides an attractive route for motorized traffic through a residential area, a negative appreciation is given to that bicycle street. If the bicycle street is only attractive for through-going cyclists, a positive appreciation is given.

The third aspect analyses whether traffic regulation measures have been applied on the bicycle street to reduce the number of through-going traffic motorized traffic on the bicycle street. Possible traffic regulation measurements could be traffic signs or cuts for motorized traffic.

The fourth aspect researches the traffic generation by buildings and houses along the street. Shops or offices along the bicycle street will generate more traffic than a house along the bicycle street. The traffic generation depends further on the building density along the street. Besides bicycle and car traffic, shops and offices will also generate truck traffic. For bicycle, car and truck traffic, the traffic generation is presented in a qualitative way. Since the main function of the bicycle street is a flow function, while traffic generation along the bicycle street belongs to an access function, a large generation of traffic is valued as negative, while a small generation is valued as positive. For bicycle traffic, the same valuation has been used, while the generation of bicycle traffic along the bicycle street is not negative. However, bicycle traffic with its origin or destination directly along the bicycle street could disturb the flowing cyclists on the street.

The fifth aspect studies the presence of public transport on the bicycle street. Public transport should not be present on a bicycle street, since the mass difference with cyclists is rather high. The presence of large vehicles such as busses does not contribute to the comfort and feeling of traffic safety on the bicycle street.

The most important results are presented in Table 5.

TABLE 5: THE ACCESS FUNCTIONS OF THE BICYCLE STREET. THE TABLE SHOWS THAT ON SOME OF THE BICYCLE STREETS NOT ONLY LOCAL MOTORIZED TRAFFIC IS EXPECTED, BUT ALSO THROUGH-GOING MOTORIZED TRAFFIC. THE TRAFFIC GENERATION OF BUILDINGS ALONG SOME OF THE BICYCLE STREETS IS RATHER HIGH. THIS COULD LEAD TO VOLUMES OF MOTORIZED TRAFFIC ON THE BICYCLE STREETS THAT ARE TOO HIGH. AGAIN, THE EXTREMES COULD BE FOUND AT THE TWO-LANE BICYCLE STREETS. FURTHER COULD BE SEEN THAT ON ALL BICYCLE STREETS ONE OR MORE TRAFFIC REGULATING MEASURES HAVE BEEN APPLIED TO REDUCE THE NUMBER OF MOTORIZED VEHICLES ON THE BICYCLE STREET.

	Two-lane bicycle streets				Single-lane bicycle streets			
	Alkmaar	Castricum	Delft	Zoetermeer	Haarlem	Houten	Oss	Zwolle
Through-going motorized traffic	--	--	++	+	+	+	0	0
Attractiveness	++	++	--	--	0	+	0	+
Traffic regulation	Moving barrier, closed between 9 p.m. and 9 a.m.	Prohibited for through-going trucks	Cul-de-sac for motorized traffic	Several cuts for motorized traffic on the bicycle street	Bicycle street continues as bicycle path at both ends	Bicycle street continues as bicycle path at one end	Cut for motorized traffic at end of bicycle street	Cul-de-sac for motorized traffic; traffic signs with mandatory directions
Traffic generation	Bicycle: 0 Car: - Truck: -	Bicycle: -- Car: -- Truck: --	Bicycle: + Car: 0 Truck: -	Bicycle: + Car: + Truck: 0	Bicycle: + Car: 0 Truck: ++	Bicycle: 0 Car: 0 Truck: +	Bicycle: 0 Car: 0 Truck: +	Bicycle: 0 Car: + Truck: +
Public transport	Two bus lines, 8 busses per hour	No	No	No	No	No	No	No

The access functions given in Table 5, show that on all the bicycle streets attention has been paid to the regulation of motorized traffic. On some of the bicycle streets these measures were successful, on other bicycle streets are the applied methods less effective. The main reasons for non-successful applied measures are often politically coloured. The presence of public transport on the bicycle street is luckily an exception, since busses do not contribute to safe and attractive bicycle streets.

3.4 Conclusions

The functions of the eight selected bicycle streets differ strongly between the bicycle streets. On the aspects of flow, urban and access functions, the bicycle streets differ from each other. It is hard to draw parallels among the different bicycle streets, even within the same type of bicycle streets. There could be noticed that the extreme values, high and low, are found at two-lane bicycle streets. This could be a bias in the small sample, but could also be an indication that two-lane bicycle streets are applied in the more extreme cases.

The wide variety in functions found at the eight selected bicycle streets shows that there is a lot of variation in streets that are turned into bicycle streets. It could therefore be concluded that bicycle streets are applied in different situations. Although the functions differ the traffic safety is not directly affected by all the differences in functions. Problems occur when the access functions of the bicycle street become prominent functions and incline to overrule the flow function for cyclists.

Considering the urban profiles of the studied bicycle streets could be concluded that most profiles contribute to the 30 km/h speed limit on the bicycle streets. Interesting is that the studied single-lane bicycle streets are all applied at a street with a pure housing function. The two-lane bicycle streets are all applied on streets with a mix of functions.

The presence of public transport on the bicycle street seems to be an exception. Public transport should not be present at a bicycle street. The large mass of a bus in comparison with the small mass of a cyclist is a serious threat for the traffic safety and the feeling of traffic safety. A bus stopping at a bus stop on the carriageway is a serious obstacle decreasing the comfort of a bicycle street for cyclists. Cyclists passing the bus could conflict with other traffic on the bicycle street.

The main conclusion is that the most important function of a bicycle street is the flow function for cyclists. A mix with access functions is possible as long as the access functions of the street are less important than the flow functions.

4 DRIVING BEHAVIOUR AND USAGE

The driving behaviour of traffic driving on the bicycle street has been investigated by observing the traffic and its movements and measuring the volumes and speeds of different vehicle categories on the bicycle street. Traffic on the bicycle street has been observed during one and an half hour per bicycle street. Speeds and volumes have been measured by road tube counters during one week.

During the observations, video recordings have been made. Based on the notes of the observations and replay of the video recordings, the behaviour on the bicycle street has been described in a qualitative way. The observations and the qualitative descriptions focussed on four main aspects: position on the road, parking, priority and speed behaviour at a micro level. Those aspects were chosen, since the pre-research gave an indication that those aspects could cause conflicts and influence the traffic safety.

The data of the road tube counters was used to get a quantitative insight in the behaviour and usage of the bicycle street. The data has been analysed to determine the volumes of different vehicle categories over the day. This information has been used to determine the traffic composition per bicycle street. Further, the speeds of different vehicle categories and the variance in average speed have been investigated. This data was used to study the speed behaviour at a macro level and to study the relation between the number of cyclists and the speed of motorized vehicles on the bicycle street.

The road tube counters provided raw data per bicycle street. The vehicles are categorized by the road tube counters in thirteen categories, according to classification scheme NLB-13. Motorized vehicles are categorized in three categories: light, medium and heavy. Vehicles in the category light are cars and vans (NLB-category 1). Vehicles in the category medium are trucks out of one part (NLB-categories 2,3 & 4). Vehicles in the category heavy are trucks out of more than one part (NLB-categories 5, 6, 7, 8, 9 & 10). Busses (NLB-category 12) have been categorized as other.

The road tube counters are able to count vehicles with a speed in a range between 10 km/h and 160 km/h. Those settings have not be modified for this study.

The data has been processed with the help of Matlab software to derive information from the data. Research within Grontmij shows that more than 95 percent of the vehicles is recorded correctly. However, the road tube counters have problems with mixed traffic on the bicycle street. Especially large groups of cyclists are often registered as heavy vehicles with a lot of axes instead of a lot of cyclists. Two cyclists driving next to each other are sometimes registered as one car driving very fast with a very short headway to its predecessor. To give a good representation of the real behaviour on the bicycle street, those cases have been filtered out of the data. The data has been filtered based on two criteria.

The first criterion is the vehicle class: vehicles categorized in NLB-class 13 are filtered out of the data. Those are vehicles with more than six axles. Vehicles classified in class 13 on a bicycle street are often large groups of cyclists, since vehicles with more than 6 axles are not expected on a bicycle street. This filtering leads to an underestimation of the number of cyclists on the bicycle street, since large groups are not always taken into account. The number of cyclists that has not been taken into account was not determined via another method, since the measurements were on another moment than the observations. No data was therefore available to determine how much cyclists passed at that particular moment.

The second criterion that has been used to filter the data is the speed in combination with the headway. Vehicles with a speed higher than 80 kilometres per hour in combination with a headway smaller than 90 seconds are filtered out of the data. At most bicycle streets it is not possible for most vehicles to reach 80 kilometres per hour, since the distance from the beginning of the bicycle street to the road tube counters is too small to accelerate to 80 km/h. Especially when there is other traffic on the road, it is impossible to reach such high speeds, therefore the headway should be larger than 90 seconds.

Road tube counters do not register mopeds on the bicycle street as a separate vehicle category. Mopeds are registered as light motorized vehicles in the dataset. Within Grontmij, method is used to distinguish mopeds from cars and other light motorized vehicles. Vehicles registered as light motorized vehicles and a wheel base smaller than 1.3 metres are categorized as mopeds.

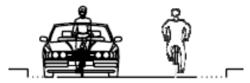
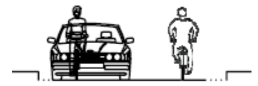
In Castricum, the municipality had recent traffic counts from March 2012 available. Therefore no road tube counters have been placed on the Dorpsstraat in Castricum. On the Dorpsstraat has not been counted with road tube counters, but has been counted by radar. Since radar measures the length of the vehicle instead of the weight, number of axles and wheel base, cyclists cannot be distinguished from mopeds. Observations at the Dorpsstraat show that most two wheelers passing are cyclists and only a few are mopeds. Therefore all two wheelers have been categorized as cyclists. So, no information about the mopeds on the Dorpsstraat is available and the number of cyclists on the Dorpsstraat is a bit overestimated.

The traffic counts on the other bicycle streets were held in the period from 22nd March to 3rd April 2013. During the weekend of 30th March, the Easter holiday was celebrated in the Netherlands. Therefore on the Friday before the weekend and especially on the Monday after this weekend, the traffic was less busy than on a normal Friday or Monday.

The aim of studying the driving behaviour on the bicycle street, is to test whether the observed behaviour is the same as the intended behaviour as described in section 1.4. The results are furhter used to test the bicycle street to the principles of Sustainable Safety in the next chapter. One of the Sustainable Safety principles that is tested is predictability. Related to this principle is the term recognisability. Whether the design is recognisable for road users and the behaviour of road users on the bicycle street is predictable has been studied by discussing the lay-outs of the eight selected bicycle streets with a traffic psychologist.

In Table 6, an overview is given of the most important results of the observations and measurements. Based on the information provided by Table 6 and the analysis per bicycle street in appendix B, a comparison is made between the two bicycle street lay-outs that are studied in this research. Based on the analysis per bicycle street, general conclusions are drawn per lay-out. Both lay-outs arecompared per statement and the statement will be accepted or rejected.

TABLE 6: AN OVERVIEW OF THE MOST IMPORTANT RESULTS OF THE EMPIRICAL RESEARCH PER BICYCLE STREET. IF APPLICABLE, COLOURS INDICATE WHETHER THE RESULTS ARE WITHIN SAFE LIMITS OR NOT. THOSE SAFE LIMITS ARE GIVEN BELOW THE TABLE AND ARE BASED ON LITERATURE STUDIES. SO IS A SPEED OF 30 KM/H CONSIDERED AS SAFE AND INCREASES THE MORTALITY RISK FOR NON-MOTORIZED ROAD USERS RAPIDLY AT HIGHER SPEEDS (WEGMAN & AARTS, 2006). THE CHOSEN RANGES FOR A SAFE SPEED ARE THEREFORE RATHER SMALL. ONE COULD EASILY SEE THAT THE SPEEDS OF MOPEDS AND MOTORIZED VEHICLES ARE TOO HIGH ON BOTH TYPES OF BICYCLE STREETS. FURTHER ARE THE VOLUMES OF THE DIFFERENT USER CLASSES PRESENT ON THE BICYCLE STREET COLOURED. IN THE DETERMINATION OF THE LIMITS, THE PRINCIPLE THAT A BICYCLE STREET IS A BICYCLE FACILITY AND THAT ONLY LOCAL MOPEDS AND MOTORIZED VEHICLES SHOULD BE PRESENT ON THE BICYCLE STREET IS USED. ON SOME OF THE BICYCLE STREETS, THE VOLUME OF MOPEDS AND MOTORIZED VEHICLES COULD BE CONSIDERED AS HIGH. ON ALL BICYCLE STREETS, THE VOLUME OF CYCLISTS IS LARGE.

		Two-lane bicycle street				Single-lane bicycle street			
		Alkmaar	Castricum	Delft	Zoetermeer	Haarlem	Houten	Oss	Zwolle
Position on the road	*With cyclists*								
	Without cyclists								
Priority	*Bicycle street priority?*	✓	✓	✓	✓	✓	✓	✓	✓
	Conflicts	Yes, cars underestimate gap between cyclists on bicycle street	Yes, cyclists from side street do not give priority to bicycle street	No	Pedestrian-car	No	No	No	No
Parking	*Parking spots*	✗	✓	✓	✗	✓	✓	✓	✓
	Conflicts	Supplying trucks block one carriageway	Supplying trucks block one carriageway	No	Yes, vehicles parked on bicycle street	No	Stopping vehicle blocks one half of street	Stopping vehicle blocks one half of street	Stopping vehicle blocks one half of street
Speed	*Speed limit*	30 km/h	30 km/h	30 km/h	30 km/h	30 km/h	30 km/h	30 km/h	30 km/h
	Speed bumps	✗	✗	✗	✓	✓	✓	✗	✗
	Mean cyclists	19.8 km/h	18.1 km/h	18.1 km/h	18.9 km/h	17.4 km/h	17.8 km/h	17.7 km/h	18.7 km/h
	Mean moped	32 km/h	-	20 km/h	36 km/h	28 km/h	33 km/h	29 km/h	28 km/h
	Mean motorized	37 km/h	30 km/h	26 km/h	27 km/h	28 km/h	27 km/h	30 km/h	27 km/h
	V85 moped	46.8 km/h	-	22.4 km/h	46.1 km/h	38.3 km/h	45.2 km/h	45.2 km/h	41.5 km/h
	V85 motorized	46.2 km/h	38 km/h	37.3 km/h	37.1 km/h	35.3 km/h	33.6 km/h	41.5 km/h	38.5 km/h
	% mopeds too fast	56 %	-	0 %	73 %	48 %	60 %	44 %	42 %
	% motorized too fast	82 %	51 %	32 %	41 %	41 %	32 %	51 %	38 %
Ratio	*Mean workday volume cyclists*	2336	3004	2562	1254	1043	1311	1254	2327
	Mean workday volume moped	652	-	12	303	183	185	233	274
	Mean workday volume motorized	2356	4410	784	121	1076	1014	393	489
	Ratio cyclists/ motorized	1.0	0.7	3.3	10.4	1.0	1.3	3.2	4.8

	Mean moped	Mean motorized	V85 moped	V85 motorized	% mopeds too fast	% motorized too fast	Mean workday volume cyclists	Mean workday volume moped	Mean workday volume motorized	Ratio cyclists/motorized
Green	0-30 km/h	0-30 km/h	0-33 km/h	0-33 km/h	0-15 %	0-15 %	>2000	<100	<1000	>1
Yellow	31-35 km/h	31-35 km/h	34-37 km/h	34-37 km/h	15-25 %	15-25 %	1000-2000	100-200	1000-2000	1
Red	36+ km/h	36+ km/h	38+ km/h	38+ km/h	25+ %	25+ %	<1000	>200	>2000	<1

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4.1 Difference between single-lane and two-lane bicycle streets

On two-lane bicycle streets, a separate carriageway per direction is available. It is possible to drive over the median. Cyclists drive on the right-hand side of their carriageway, instead of in the middle of their carriageway as intended. This is normal behaviour, since cyclists are forced by law to drive at the right-hand side of the road. By driving on the right-hand side of their carriageway, cyclists are passed easier by cars. Many cars pass cyclists they are approaching directly. They only stay behind the cyclist when a car or a group of cyclists in the opposite direction approaches. In that case, there is no space available to pass the cyclist. Also when a group of cyclists drives in front of the car, cars are eager to pass this group.

At this type of bicycle streets, many cars drive in the middle of the street with two wheels on each side of the median. In this position, it is possible to pass cyclists on their own carriageway while cyclists in the other direction approach, since the dimensions of this lay-out are quite large.. Of course, this is only possible when no other vehicles or groups of cyclists are approaching. Two carriageways of 2.5 metres plus a median of 1 metre generate a width of 6 metres. There is therefore enough space to pass a cyclist, while other cyclists are approaching.

On single-lane bicycle streets, all the vehicles in both directions have to share the same asphalt strip. Most cyclists use this asphalt strip. Cars stay behind the cyclists and have to drive with two wheels on the rabat strip, since cyclists in the opposite direction are driving on this asphalt strip as well. Cars can only pass a cyclist when cyclists in both directions move to the rabat strip or when no cyclist is approaching in the opposite direction. The first situation does not often occur, so cars have to wait until there is no traffic in the opposite direction. This could be related to the narrower dimensions of the bicycle street: one asphalt strip of 3.5 meters and two rabat strips of 0.75 meters give a width of 5 metres.

The rabat strips are used by some cyclists. Especially in large groups of cyclists, cyclists cycle with three or four cyclists next to each other and the rabat strip is then used as extra driving space. In a couple of cases, the rabat strip is used by cyclists while there is no other traffic on the bicycle street. On the single-lane bicycle street, large groups of cyclists tend also to use the complete width of the asphalt strip, especially when the bicycle flow in the opposite direction is small.

On all the bicycle streets, conflicts have been observed. A conflict is in this case defined as two participants approaching each other who will crash into each other when none of both participants will change direction or speed. Luckily, in all the conflicts that have been observed, at least one of the participants changed direction or speed and conflicts did not become crashes.

4.2 Priority on bicycle streets

At every bicycle street, at least one intersection between the bicycle street and another street has been observed. In most cases, the traffic flow on the crossing street was rather small, especially compared with the traffic flow on the bicycle street. On all the observed intersections, traffic on the bicycle street had priority over traffic entering or crossing the street.

During the observations, only in a few cases conflicts between traffic crossing or entering the bicycle street and traffic on the bicycle street have been observed. The most occurring conflict was a car taking a too small gap between two cyclists. This caused no real conflicts, since cyclists anticipated on the car. However, on most bicycle streets, the crossing traffic flow was very small, so not that many crossing vehicles have been observed at all.

Special conflicts observed on the bicycle street were cyclists crossing the bicycle street without giving priority to the cars on the bicycle street. Cars on the bicycle street had to brake to avoid a crash.

Another conflict has been observed between a pedestrian following the bicycle street and cars crossing the bicycle street. The pedestrian did officially not have priority, but a car in one direction gave priority to the pedestrian. A car in the other direction did not give priority to the pedestrian, while the pedestrian expected to get priority. An emergency stop of the car was the result.

However, in general could be concluded that by giving priority to the bicycle street, the traffic situation on intersections becomes clear. Since the traffic flow on the bicycle street is much higher than on the side streets, giving priority to the bicycle street feels natural. The traffic situations on intersections along the bicycle streets are therefore more predictable.

The conflicts that have been observed are all observed on two-lane bicycle streets. A possible explanation could be found in the design of the intersections in both types of bicycle streets. Two-lane bicycle streets often have intersections where priority is regulated by traffic signs and shark's teeth on the asphalt, while single-lane bicycle streets contain intersections where priority is regulated by a continuous sidewalk. In the first case, it is often possible to enter or cross the bicycle street with a high speed, while in the second case the speed is low because of the intersection design.

4.3 Parking along bicycle streets

In general, the observation periods were too short to observe enough arriving or departing cars at the bicycle street. In most cases, there was no other traffic on the bicycle street when cars were parked in or left a parking spot. Only in Oss a conflict has been observed. A driver left the parking spot without looking at the other traffic on the street. Two cyclists had to brake in order to prevent a crash. Based on this one observation, no conclusions could be drawn. It is not excluded that this conflict arose by chance.

Only two bicycle streets did not have parking spots along the bicycle street. In one case, this did not cause problems, since the parking demand was facilitated by parking spots in surrounding streets. In the other case, many vehicles were parked on the bicycle street itself and were an obstacle for cyclists and other traffic on the bicycle street. A car passing the parked cars blocked the street and cyclists had to brake and wait for the car.

Another aspect that has been observed is the danger of opened doors blocking the bicycle street. One of the advantages of the single-lane bicycle street should be that the rabat strip functions as a safety zone between parked cars and the bicycle street. However, this safety zone is also used by some cyclists on the bicycle street. In case of a two-lane bicycle street, this safety zone is not available in the design and therefore only applied per parking spot. Cyclists are not using this safety zone, since it does not continue along the bicycle street. At some single-lane bicycle streets, conflicts have been observed between parked cars with opened doors and cyclists on the rabat strip.

Further were temporarily parked vehicles observed on the bicycle street for the supply of shops and businesses along the bicycle street. This has been observed on several bicycle streets. On all those bicycle streets, one of the carriageways or one half of the carriageway was blocked by the supplying vehicle. Cyclists and other traffic had to pass along the stopped vehicle. This caused conflicts, since the view along the stopped vehicle was not very good.

It could be concluded that the observed conflicts indicate that the access function for cars and flow function for cyclists of the bicycle street are conflicting with each other. The access function is represented by the parking and stopping vehicles on the bicycle street, while cyclists flowing on the bicycle street are trying to pass the vehicles.

4.4 SPEEDS ON BICYCLE STREETS

The speed of motorized vehicles on the bicycle street has been studied at macro level and micro level. At macro level, the average speeds and volumes are used to derive general conclusions about the speed behaviour on the bicycle street. Input for this study was the data from the road tube counters. At micro level, the speed behaviour of motorized vehicles in the neighbourhood of cyclists are described. For the last situations, there is no quantitative data available, so the speed behaviour is described in a qualitative way.

At a macro level, the average speeds and speed distributions of the different vehicle categories present on the bicycle street were studied and compared. Besides the average speed, also the V85-values of mopeds and motorized vehicles have been studied. The speed distributions of light motorized vehicles are shown in Figure 10.

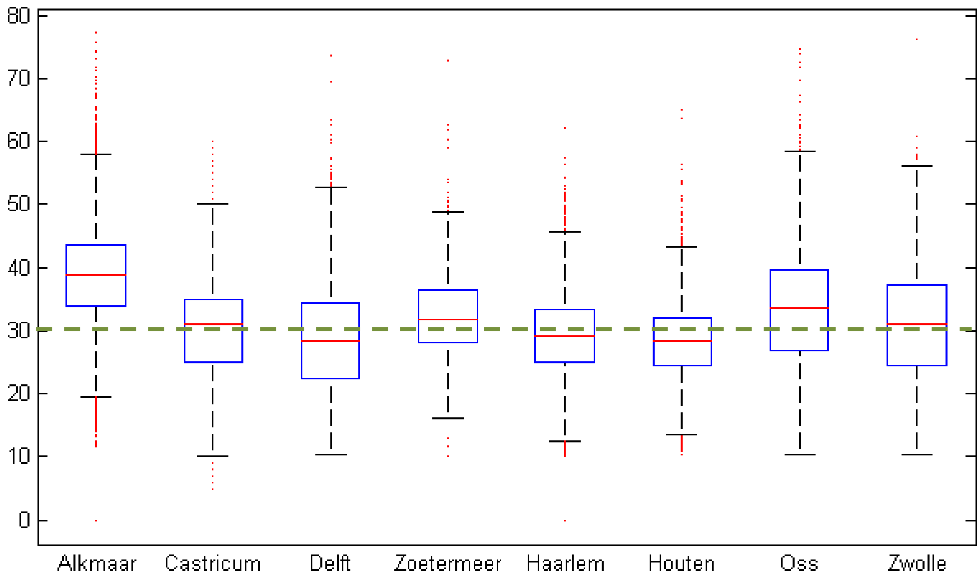

FIGURE 10: THIS BOXPLOT SHOWS THE SPEED DISTRIBUTIONS OF LIGHT MOTOR VEHICLES ON WORKDAYS ON THE EIGHT STUDIED BICYCLE STREETS. THE RED HORIZONTAL LINE REPRESENTS THE MEDIAN OF THE POPULATION. 25% OF THE DATA ABOVE AND BELOW THE MEAN SPEED ARE INDICATED BY THE BLUE HORIZONTAL LINES, SO THE BOX CONTAINS 50% OF THE MIDDLE DATA. DATA OUTLIERS ARE REPRESENTED BY RED DOTS BELOW OR ABOVE THE WHISKERS. THE GREEN DOTTED LINE SHOWS THE 30 KM/H SPEED LIMIT ON THE BICYCLE STREETS. THE BOXPLOT SHOWS THAT THE SPEEDS ON THE BICYCLE STREET IN ALKMAAR DIFFER FROM THE OTHER BICYCLE STREETS.

In Figure 10 can be seen that median speeds of light motorized vehicles on seven bicycle streets are more or less at the same level. The median speed on the bicycle street in Alkmaar is much higher than the median speeds of the other bicycle streets. Therefore the differences between the mean speeds have been tested on a 95% significance level. The results of this test show that the mean speeds of the bicycle streets in Castricum and Zoetermeer do not significantly differ from each other. Also the mean speeds of motorized vehicles on the bicycle streets in Haarlem and Zwolle do not differ significantly from each other. The other means do significantly differ from the means of other bicycle streets. So the mean speed on the bicycle street in Alkmaar is significantly higher than the mean speeds of the other bicycle streets. The means differ significantly mainly due to the large spread of speeds on some bicycle streets.

The speeds shown in Figure 10 are measured during five workdays. In some cases, cars passed the road tube counters while there were no cyclists present on the bicycle street, in other cases cyclists were present. It is not possible to make a distinction in the data between cars driving with or without cyclists on the street. However, with or without cyclists, a speed lower than 30 km/h is considered as a safe speed (Wegman & Aarts, 2006). Based on the green line in Figure 10 indicating the 30 km/h speed limit could be concluded that on most bicycle streets a large part of the light motor vehicles drives faster than the safe speed.

It is not expected that the speeds of cyclists differ that much per bicycle street. The speeds of cyclists have been investigated and plotted in a box plot in Figure 11. Since in Castricum traffic has been counted with radar instead of road tube counters, cyclists driving slower than 10 km/h have been counted. Road tube counters are not able to measure vehicles driving slower than 10 km/h.

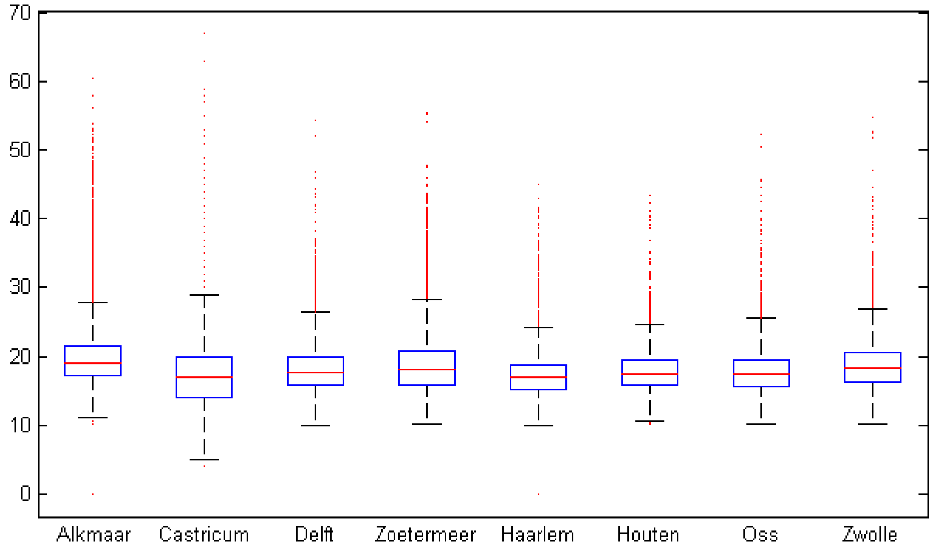

FIGURE 11: THIS BOXPLOT SHOWS THE SPEED DISTRIBUTIONS OF CYCLISTS ON THE DIFFERENT BICYCLE STREETS. THE MEDIAN SPEEDS AND SPEED DISTRIBUTIONS OF CYCLISTS ARE COMPARABLE ON ALL BICYCLE STREETS.

In Figure 11 can be seen that the mean speeds of cyclists all are around 18 km/h. On a first sight, the mean speeds seem not to differ per bicycle street. The mean speeds have been tested on a 95% significance level. Only the speeds on the bicycle streets in Castricum and Delft and the speeds on the bicycle streets in Houten and Oss do not differ significantly. However, the differences are small and hardly relevant for the rest of this study.

Not only the speeds of cyclists and light motorized vehicles have been studied, but also the speeds of mopeds driving on the bicycle streets. An overview of those speeds is given in the box plot in Figure 12. The bicycle street in Castricum has been left out of this plot since no data about the speed of mopeds on this bicycle street was available.

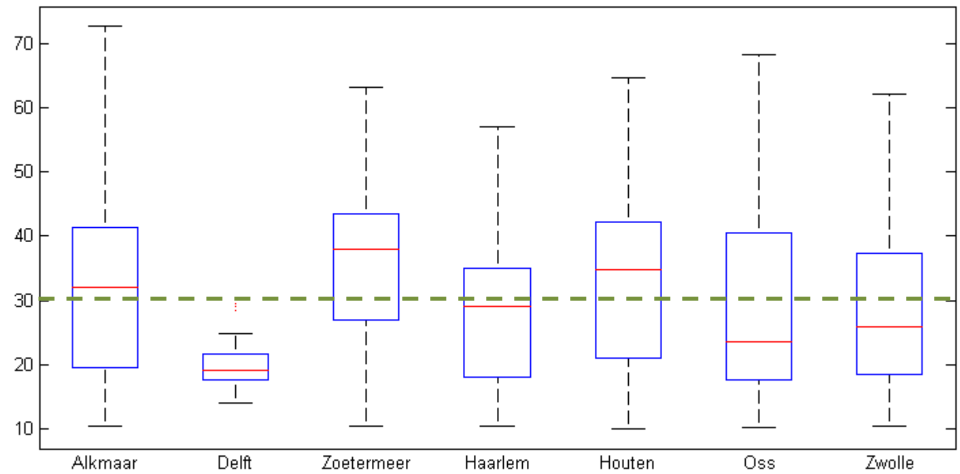

FIGURE 12: THIS BOXPLOT SHOWS THE SPEED DISTRIBUTION OF MOPEDS ON THE BICYCLE STREET. THE 30 KM/H SPEED LIMIT IS GIVEN BY THE GREEN DOTTED LINE. THE BOXPLOT SHOWS THAT THE MEDIAN SPEEDS AND SPEED DISTRIBUTIONS DIFFER STRONGLY PER BICYCLE STREET. HOWEVER, ON MOST BICYCLE STREETS, A LARGE PART OF THE MOPEDS ON BICYCLE STREETS DRIVES TOO FAST.

In Figure 12 can be seen that the mean speeds of mopeds on the bicycle streets are often quite high. Also the large variance of speeds, especially in the higher speed regions is remarkable. Further investigation in the speeds of mopeds shows that on most bicycle streets, two speed groups of mopeds exist. One group contains speeds around 20 km/h while the other group contains speeds around 40 km/h and sometimes even above. The first group has a small speed difference with cyclists while the other group has a large speed difference. This second group is the most dangerous one due to its driving style and speed choice and needs therefore the most attention.

The mean speeds of cyclists, light motorized vehicles and mopeds have been compared. Furthermore, the averages per bicycle street design have been calculated. Also the weighted averages have been calculated, taking the volumes on the bicycle street into account. Those weighted averages make a more fare comparison between the two types of bicycle streets possible. Those averages can be found in Table 7.

TABLE 7 SHOWS SPEEDS AND AVERAGE SPEEDS OF MOTORIZED VEHICLES, MOPEDS AND CYCLISTS ON BICYCLE STREETS. SPEEDS IN KM/H, VOLUMES IN VEHICLES/DAY. THERE CAN BE SEEN THAT THE SPEEDS ON TWO-LANE BICYCLE STREETS ARE HIGHER THAN ON SINGLE-LANE BICYCLE STREETS. AN IMPORTANT EXPLANATION FOR THIS DIFFERENCE COULD BE FOUND IN THE HIGH SPEEDS ON THE BICYCLE STREET IN ALKMAAR.

		Two-lane bicycle streets						Single-lane bicycle streets					
		Alkmaar	Castricum	Delft	Zoetermeer	**Averages**	**Weighted averages**	Haarlem	Houten	Oss	Zwolle	**Averages**	**Weighted averages**
Motorized	*Mean speed*	37	30	26	27	**30**	**31.7**	28	27	30	27	**28**	**27.8**
	V85	46.2	38	37.3	37.1	**39.7**	**40.4**	35.3	33.6	41.5	38.5	**37**	**36.1**
	Workday volume	2356	4410	784	121	**1918**		1076	1014	393	489	**743**	
Moped	*Mean speed*	32	-	20	36	**22**	**33.1**	28	33	29	28	**30**	**29.3**
	V85	46.8	-	22.4	46.1	**28.8**	**46.3**	38.3	45.2	45.2	41.5	**43**	**42.6**
	Workday volume	652	-	12	303	**242**		183	185	233	274	**219**	
Cyclist	*Mean speed*	19.8	18.1	18.1	18.9	**18.7**	**18.6**	17.4	17.8	17.7	18.7	**18**	**18.1**
	Workday volume	2336	3004	2562	1254	**2289**		1043	1311	1254	2327	**1484**	

In Table 7 is shown that the average speeds of the different vehicle categories on the bicycle street differ between the two bicycle street lay-outs. Considering the weighted averages, the speeds of all vehicles are higher on two-lane bicycle streets than on single-lane bicycle streets. A possible explanation could be found in the different dimensions of the profiles. Therefore, the distance from house front to house front, the width of the traffic space and the asphalt strip of the bicycle street are given in Table 8.

TABLE 8 GIVES THE DIMENSIONS OF THE CROSS-SECTIONAL PROFILE OF THE DIFFERENT BICYCLE STREETS. THE DIMENSIONS HAVE BEEN DERIVED FROM DESIGN DRAWINGS, LOCAL MEASUREMENTS AND MEASUREMENTS IN GOOGLE EARTH. THE GIVEN DIMENSIONS GIVE A GOOD INDICATION OF THE WIDTH OF THE BICYCLE STREET, BUT COULD VARY A BIT ALONG THE BICYCLE STREET.

	Two-lane bicycle street				Single-lane bicycle street			
	Alkmaar	Castricum	Delft	Zoetermeer	Haarlem	Houten	Oss	Zwolle
Distance house front to house front [m]	30	16	12	40	15	20	18	18
Width traffic space [m]	6	6	4.8	4	4.5	4.5	5	4.5
Width asphalt strip [m]	2x 2.5	2x 2.1	2x 2	2x 1.75	3	3.5	3.5	3.5

Based on the dimensions in Table 8 and the average speeds in Table 7, no relation between the distance from house front to house front is and the average speed could be found. However, a relation between the width of the traffic space or the asphalt strip and the average speed is expected. To investigate whether the dimensions and the speed are correlated, two scatter plots have been made. In Figure 13, the average speeds of mopeds, cyclists and motorized vehicles have been plotted versus the width of the traffic space. This is the distance between the curbs. In Figure 14, the average speeds of mopeds, cyclists and motorized vehicles have been plotted versus the width of the asphalt driving strip. Since the four two-lane bicycle streets have two separated driving strips, the total width of the two driving strips has been used.

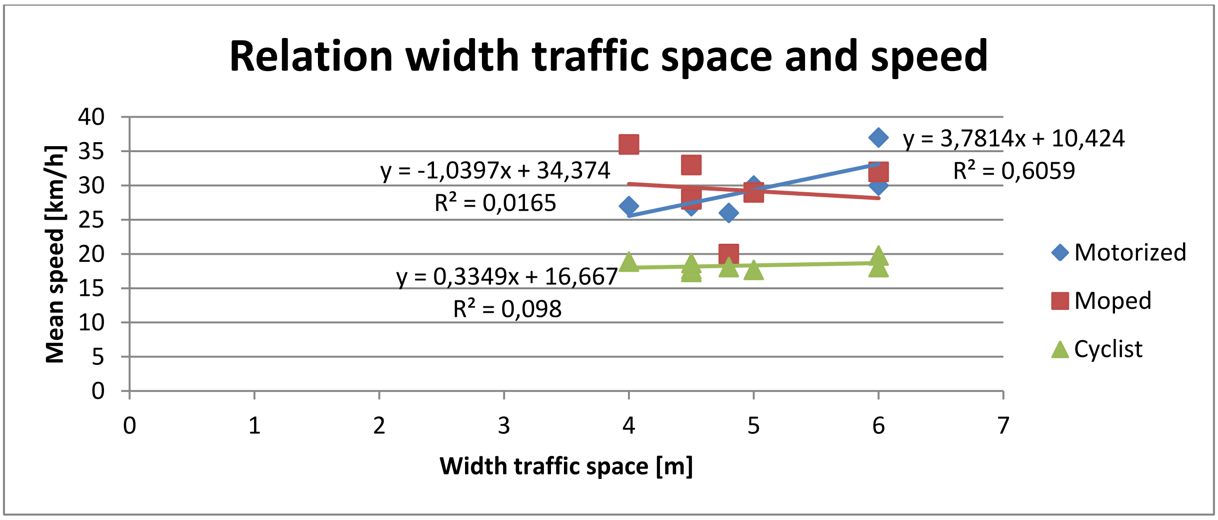

FIGURE 13 SHOWS THE RELATION BETWEEN THE WIDTH OF THE TRAFFIC SPACE AND THE AVERAGE SPEEDS OF MOTOR VEHICLES, MOPEDS AND CYCLISTS. ONLY FOR MOTOR VEHICLES AN INDICATION FOR A RELATION BETWEEN THE AVERAGE SPEED AND THE WIDTH OF THE TRAFFIC SPACE COULD BE FOUND.

In Figure 13 can be seen that there is a relation between the width of the traffic space and the average speed of motorized vehicles. A narrow street will have lower speeds of motorized vehicles, while a wide street will have higher speeds of motorized vehicles. A possible relation between the number of cyclists on the bicycle street and the driven speed are discussed in the next section. There is no relation between the width of the traffic space and the speeds of mopeds and cyclists.

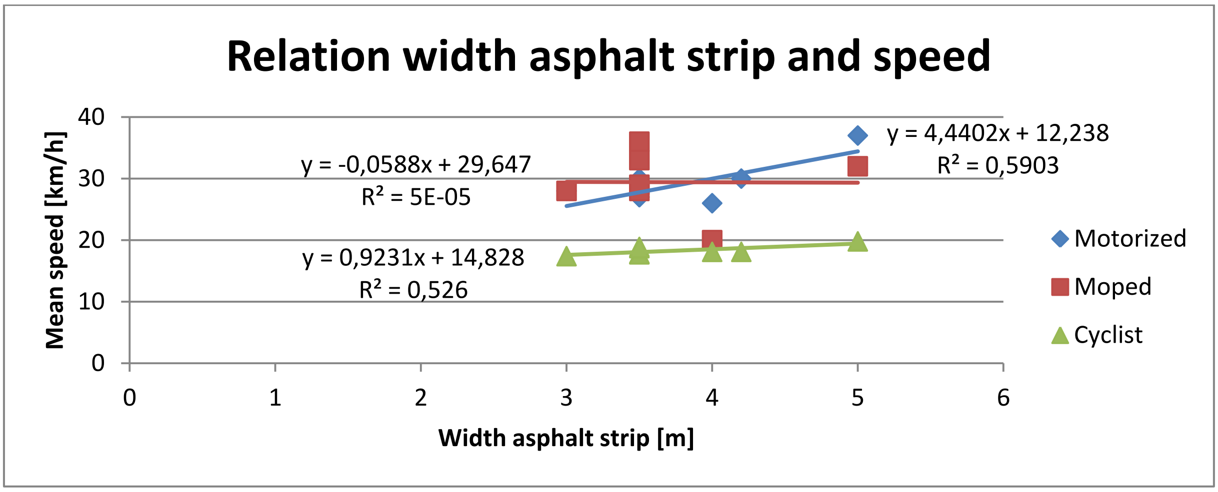

FIGURE 14 SHOWS THE RELATION BETWEEN THE WIDTH OF THE ASPHALT STRIP AND THE AVERAGE SPEED OF MOTOR VEHICLES, MOPEDS AND CYCLISTS. THERE IS AN INDICATION THAT A RELATION BETWEEN THE WIDTH OF THE ASPHALT STRIP AND THE AVERAGE SPEEDS OF MOTOR VEHICLES AND CYCLISTS EXISTS.

In Figure 14 can be seen that the speed of motorized vehicles is also affected by the width of the asphalt strip at the bicycle street. Further, there is a relation between the width of the asphalt strip and the speed of cyclists on the bicycle street. The speed of mopeds is not affected by the width of the traffic space nor the width of the asphalt strip on the bicycle street.

Regarding the statement could be concluded that at macro level cyclists and motorized vehicles do not drive the same speed. However, the speed differences are small and mean speeds below 30 km/h and V85-values just above 30 km/h indicate that a large part of the cars on the bicycle street drives at a safe speed. However, the volume of cars driving slower than 30 km/h should be increased to improve the traffic safety. This can be done by the application of a narrower profile or speed bumps on the bicycle street.

The high speeds of mopeds on the bicycle street are a problem, especially since the speed choice of mopeds is not affected by the dimensions of the bicycle street. Even speed bumps on the bicycle street do not seem to affect the speed of mopeds. In Zoetermeer, Haarlem and Houten, speed bumps have been applied on the bicycle street, but the V85-values of mopeds are the same as on other bicycle streets. Mopeds drive as fast as possible and do not commit to any speed limit.

The speeds on the bicycle street have also been studied at micro level. The main focus is on the speeds of cars while passing one or more cyclists. Since those passing manoeuvres are rather short and not predictable, no quantitative data is available on the speeds of passing vehicles. Nevertheless, based on the observations a qualitative description is made.

So has been observed at two-lane bicycle streets that cars only stay behind the cyclists when a car in the opposite direction is approaching. The profile is that wide that it is possible to pass a cyclist with a rather high speed since the space between the cyclist and the car is rather large.

If a car is following a large group of cyclists, the car will pass the group when there is no traffic in the opposite direction. The speed of the passing car depends on the traffic flow in the opposite direction. When the flow is small, the gaps in the flow will be large. The pass manoeuvre could therefore take a long time and the speed will be low. When the flow is large, the gaps will be small. A passing vehicle will therefore drive fast in order to fit into the gap.

The speed depends also on the size of the group. When the group of cyclists is large, the car will have to pass with a rather high speed since otherwise the manoeuvre will take too much time. If only a few cyclists are present in front of the car, the speed will be lower since there is time enough for the manoeuvre.

On two-lane bicycle streets, cars tend to pass cyclists directly, often without adjusting their speed. On single-lane bicycle streets, cars lower their speed when there is a cyclist on the street and only pass the cyclist when there is no traffic coming in the opposite direction. The speed of the passing car is low, since the space between the car and the cyclist is small.

4.5 Ratio cyclists/motorized vehicles on bicycle streets

According to the design guidelines for bicycle streets, a street can be reconstructed into a bicycle street when there are at least twice as much cyclists than cars on the bicycle street. In this statement is stated that not necessary twice as much cyclists than cars should be on the bicycle street, but more cyclists than cars should be needed to enforce a low speed of motorized vehicles.

To investigate whether there is a relation between the number of cyclists and the speed of cars on the bicycle street, the ratio cyclists/motorized vehicles has been calculated. There has been chosen to investigate the ratio, since in the design guidelines often is spoken about a ratio between the number of cyclists and the number of motorized vehicles on the bicycle street. The ratios per bicycle street and per day period have been calculated and are given in Figure 15.

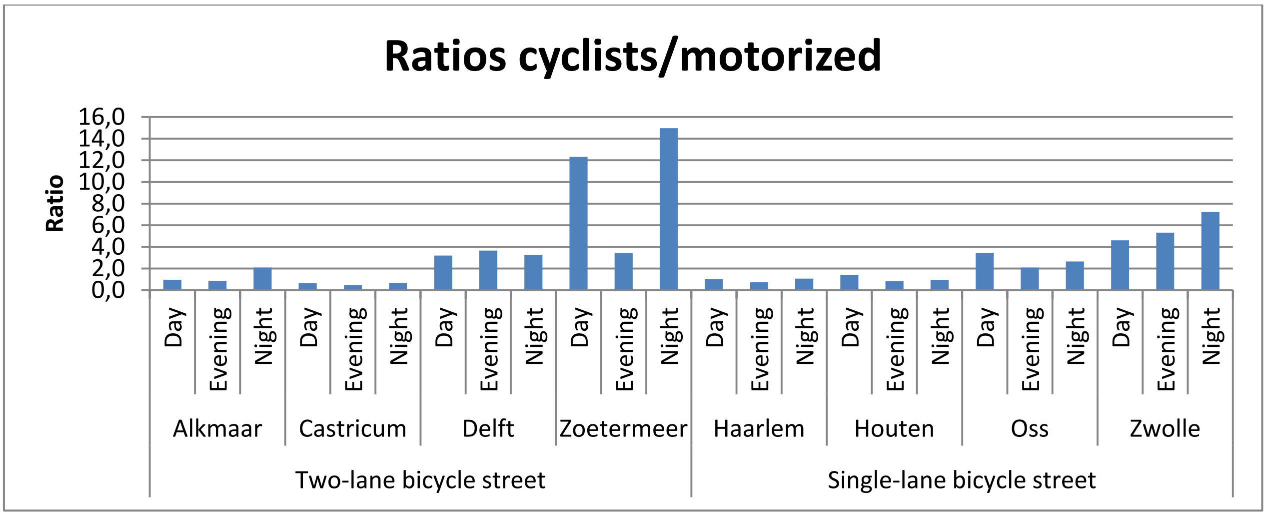

FIGURE 15 SHOWS THE RATIOS CYCLISTS/MOTORIZED VEHICLES PER BICYCLE STREET AND DAY PERIOD. THE RATIOS DIFFER STRONGLY PER BICYCLE STREET, BUT DO NOT CHANGE THAT MUCH DURING THE DAY. THE RATIOS ARE QUITE HIGH IN ZOETERMEER DUE TO THE SMALL VOLUME OF MOTOR VEHICLES ON THAT BICYCLE STREET. THERE IS NO INDICATION THAT THE RATIOS DIFFER BETWEEN THE TYPES OF BICYCLE STREET.

Figure 15 shows that four of the eight studied bicycle streets do not follow the guideline as provided by Andriesse and Ligtermoet (2005) and in the Design manual for bicycle traffic (2007) of at least twice as much cyclists as motorized vehicles on the bicycle street. The ratios have been compared with the mean speeds in Table 7, and on the first sight no relation between the ratio and the mean speed has been found.

However, the relation between the ratio cyclists/motorized vehicles and the speed of motorized vehicles has been investigated per bicycle street, because in earlier research (Meijboom & Prikken, 1994; Andriesse & Hansen, 1996; Andriesse & Ligtermoet, 2005) is stated that more cyclists than cars are needed to gain the desired behaviour of cars and mopeds and to enforce them to drive with a low speed. In this investigation, the average speed of motorized vehicles per hour of a workday and ratio in that hour have been plotted in a scatter plot. Those scatter plots can be found in appendix B. In the case that the average speed should depend on the ratio, a trend line in the scatter plot should indicate a negative correlation between the speed and the ratio. The R^2-value of the trend line indicates how well the known values predict the unknown values. The higher the R^2-value, the better the predictions that are given by the formula of the trend line. If the relation between the ratio and the average speed is strong, the R^2-value will be high.

The study among the eight selected bicycle streets shows that at most bicycle streets, no correlation between the ratio cyclists/motorized vehicles and the average speed of motorized vehicles is found. At some bicycle streets, an indication of a relation is found. However, the R^2-values in those cases are quite low ($R^2 < 0.3$), indicating that the relation between the ratio and the average speed is not strong.

Since no correlation is found between the ratio cyclists/motorized vehicles and the average speed of motorized vehicles could be concluded that more cyclists than cars do not enforce a low speed. The speeds were plotted versus the average volumes of cyclists on the bicycle street. These plots show that the average speed of motorized vehicles decreases when the volume of cyclists increases.

Therefore, the average volumes of cyclists versus the average speeds of motorized vehicles were plotted in a scatter plot per bicycle street. Per scatter plot, a trend line has been drawn. The formula and R^2-value show that there is a relation between the number of cyclists on the bicycle street and the average speed of motorized vehicles on two-lane bicycle streets. The relation is quite strong (R^2-value > 0.5) and the formula indicates a negative relation between the number of cyclists and the average speed of cyclists. At single-lane bicycle streets, this relation is present at some of the bicycle streets, with the R^2-value is much smaller (R^2-value < 0.2).

These results indicate that at two-lane bicycle streets, the average speed of motorized vehicles depends on the number of cyclists on the bicycle street, while at single-lane bicycle streets, the speed choice of motorized vehicles is independent of the number of cyclists on the street. A possible explanation could be found in the dimensions of the two-lane bicycle street and the single-lane bicycle street of the street. The speed choice of motorized vehicles on single-lane bicycle streets probably depends on the small dimensions of this type of bicycle streets.

The two-lane bicycle street is wider, so when the volume of cyclists is low, cars can easily pass the cyclists. When the number of cyclists grows, cars will be confronted with more cyclists. This effect could be compared with the levels of service on motorways. With more cyclists on the street, the level of service for cars will decrease. With a decrease in the level of service, also the speed will decrease.

4.6 Recognisability and predictability of the bicycle street design

The recognisability of bicycle streets and predictability of the behaviour of traffic participants has been studied based on the knowledge field of Human Factors. In an interview with a traffic engineer in Grontmij, who had additional education in the field of traffic and Human Factors, the different bicycle streets have been discussed.

Since bicycle streets are quite a new phenomenon in the Netherlands and the lay-outs differ from each other, many road users do not have a mental profile of a bicycle street. Drivers will react on new designs according to general 'rules' within their head, telling them how to react in certain traffic situations (Harms & Dicke-Ogenia, 2011). Those rules form a mental profile per design element, containing the reaction of a driver on a design element. A mental profile helps road users to couple design and driving behaviour. By frequently facing the same designs, the mental profile will grow and road users will know what driving behaviour is expected.

Cyclists should behave like they are cycling on a bicycle path and motorized vehicles should have the feeling that they are on a bicycle path and should therefore anticipate on the cyclists on the bicycle path. At the same time is it important that cyclists expect cars on the bicycle street. The design of a bicycle street should be associated with the same mental profile as the design of a bicycle path. To achieve this, a bicycle street should look like a bicycle path in more aspects than only the application of red-coloured asphalt on the street.

The two-lane bicycle street design will not be associated with the mental profile of bicycle path for several reasons. The first reason is the wide profile of this type of bicycle streets. This wide profile will be associated with a normal road instead of a bicycle path. Cyclists will therefore cycle on the right-hand side of the road and cars will pass the cyclists. The median does not contribute to the recognisability as a bicycle path, since normal bicycle paths do not have a median. The median causes a visual division between the two driving directions, suggesting homogeneity in driving directions. This suggestion will not help to enforce a low speed on the bicycle street.

The single-lane bicycle street design could be associated with the mental profile of a bicycle path. The small red-coloured driving strip in the middle of the street will be associated with a cycle path due to the small dimensions of the strip and cyclists driving in both directions on the strip. If the rabat strips are not too wide and have the same pattern as the gutter along the bicycle street, cyclists will associate the rabat strip with the gutter and not cycle on the rabat strip. The rabat strip will be associated with the mental profile of a gutter.

Figure 16 shows a detail of a bicycle street where the gutter and rabat strip are integrated. Figure 17 shows a detail of a bicycle street where the rabat strip and gutter are separated. In the situation as shown in Figure 16, the rabat strip will be associated with the mental profile of a gutter, while in Figure 17, the rabat strip will not be associated with a gutter, since the gutter is separated.

FIGURE 16: THE RABAT STRIP AND GUTTER ARE INTEGRATED ON THIS BICYCLE STREET. THE APPLICATION OF A GULLEY IN THE RABAT STRIP MAKES THE RABAT STRIP UNATTRACTIVE FOR CYCLISTS.

FIGURE 17: THE RABAT STRIP AND GUTTER ARE SEPARATED ON THIS BICYCLE STREET. CYCLISTS WILL THEREFORE NOT ASSOCIATE THE RABAT STRIP WITH A PLACE WHERE THEY NOT SHOULD CYCLE.

When the rabat strip is too wide, the rabat strip will be associated with bicycle lanes and cyclists will use the rabat strip instead of the asphalt driving strip. This could further be prevented by enlarging the discomfort of the rabat strips by using for example rubbles.

By adding bicycle path lane lining in the middle of the street, the association with the mental profile of a bicycle path could be strengthened. The bicycle street in Haarlem, shown in Figure 18, has already such lane lines in the middle of the street.

FIGURE 18: BICYCLE STREET IN HAARLEM WITH BICYCLE PATH LANE LINE IN THE MIDDLE OF THE STREET. THIS LANE LINE HAS BEEN ADDED LATER, WHEN AN EVALUATION AMONG USERS SHOWED THAT THE DESIGN WAS NOT CLEAR ENOUGH. THE APPLICATION OF A LANE LINE STRENGTHENED THE ASSOCIATION WITH A BICYCLE PATH.

So, to make the driving behaviour on the bicycle street predictable, the design should be associated with the mental profile of bicycle paths. The single-lane bicycle street design could be associated with the mental profile of bicycle paths. The mental profile of this type of bicycle streets could be improved by adding bicycle path lane lining in the middle of the street. Also integrating the gutter and rabat strip will help, since the mental profile of a gutter tells a cyclist not to cycle in the gutter.

However, cyclists should also be aware of the fact that cars could be present on the bicycle street. This could be achieved by the realisation of parking spots along the bicycle street and the application of one common traffic sign, differing from the traffic sign for a bicycle path.

The mental profile could be strengthened by often facing the same types of bicycle streets with the same design elements. Road users should therefore face bicycle streets with a clear profile. Mixes of profiles do not contribute to the creation of a mental profile.

4.7 Conclusions

The driving behaviour of traffic on the bicycle street has been tested to study whether the real driving behaviour is consistent with the intended driving behaviour. In Table 9, the intended behaviour and observed behaviour are summarized for the two types of bicycle streets that has been studied. Per type of bicycle street, the intended and observed behaviour per main road user category have been described.

Based on Table 9 could be concluded that the observed behaviour on the single-lane bicycle street design meets the intended behaviour better than the observed behaviour on two-lane bicycle streets. On the criteria 'position on the road' and 'speed', the single-lane bicycle street scores better than the two-lane bicycle street.

Special attention should be paid to parking and stopping vehicles on the bicycle street and the speeds of mopeds on the bicycle street. On both types of bicycle streets, those two aspects are a threat for the traffic safety on the bicycle streets.

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TABLE 9: INTENDED VERSUS OBSERVED BEHAVIOUR PER TYPE OF BICYCLE STREET

		Two-lane bicycle street			Single-lane bicycle street		
		Car	Cyclist	Moped	Car	Cyclist	Moped
Position on the road	*Intended behaviour*	Cars stay behind the cyclists on their own carriageway and only pass the median, when their own carriageway is blocked.	Cyclists cycle in the middle of their own carriageway and do not move for cars behind them. They only pass the median when their own carriageway is blocked.	Mopeds share the carriageway with cyclists. They drive therefore at the same speed as cyclists. They only pass the median when their own carriageway is blocked.	Cars drive with two left wheels on asphalt driving strip and two right wheels on rabat strip. Cars stay behind cyclists in front of them.	Cyclists cycle on the right-hand side of the asphalt strip in the middle of the street. They can pass slower cyclists via the other half of the driving strip when there is no traffic in the opposite direction.	Mopeds drive on the right-hand side of the asphalt strip and share the driving strip with cyclists. They can pass cyclists via the other half of the driving strip when there is no traffic in the opposite direction.
	Observed behaviour	Cars pass the median to pass the cyclists. Cars do not stay behind the cyclists in front of them, but take the first opportunity to pass them. They often drive with two wheels on both sides of the median when there is no other traffic.	Cyclists cycle at the right-hand side of their carriageway. Two or more cyclists will use the whole width of their carriageway and do not move for cars behind them.	Since cyclists drive at the right-hand of the carriageway, mopeds can pass cyclists easily and at a high speed. They do not brake for cyclists and manoeuvre between cyclists and cars on the bicycle street.	Cars stay behind the cyclists on the bicycle street, with two wheels on asphalt and two on rabat strip. Only when there is no traffic in the other direction, cars pass the cyclists in front of them at a low speed. When there is no other traffic, cars drive on the asphalt strip	Cyclists cycle on the asphalt driving strip. Large groups of cyclists take the whole asphalt strip and push other cyclists to the rabat strip. Some cyclists prefer the rabat strip over the asphalt driving strip, especially when the rabat strip is wide.	Mopeds drive on the asphalt strip in the middle of the street. They manoeuvre among the cyclists on the driving strip.
Priority	*Intended behaviour*	Car gives priority to the bicycle street. Car gets priority on the bicycle street.	Cyclist gives priority to the bicycle street. Cyclist gets priority on the bicycle street.	Moped gives priority to the bicycle street. Moped gets priority on the bicycle street.	Car gives priority to the bicycle street. Car gets priority on the bicycle street.	Cyclist gives priority to the bicycle street. Cyclist gets priority on the bicycle street.	Moped gives priority to the bicycle street. Moped gets priority on the bicycle street.
	Observed behaviour	Cars do not always give priority to cyclists on bicycle street. They often overestimate the gap.	Cyclists do not always give priority to the traffic on the bicycle street.	Mopeds give priority when entering the bicycle street. Mopeds get priority on the bicycle street.	Cars give priority to the bicycle street and get priority when they are on the bicycle street.	Cyclists give priority to the bicycle street and get priority when they are on the bicycle street	Mopeds give priority to the bicycle street and get priority when they are on the bicycle street
Parking	*Intended behaviour*	Vehicles should not park and stop on the bicycle street.	Inapplicable	Inapplicable	Vehicles should not park and stop on the bicycle street.	Inapplicable	Inapplicable
	Observed behaviour	Vehicles stop on bicycle street for supply.	Inapplicable	Inapplicable	Vehicles stop on bicycle street for supply.	Inapplicable	Inapplicable
Speed	*Intended behaviour*	Car drives at a low and safe speed, 30 km/h or lower.	Cyclist drives at the speed preferred by him/herself.	Moped drives at a low and safe speed, 30 km/h or lower.	Car drives at a low and safe speed, 30 km/h or lower.	Cyclist drives at the speed preferred by him/herself.	Moped drives at a low and safe speed, 30 km/h or lower.
	Observed behaviour	Speed of cars depends strongly on the profile, at most bicycle streets, speeds lie around 30 km/h.	Cyclists drive at their own preferred speed. Pass other, slower cyclists if necessary.	A large part of the mopeds drives much faster than 30 km/h. The speed does not depend on the profile or the number of speed bumps.	Speed of cars depends strongly on the profile, at most bicycle streets, speeds lie around 30 km/h.	Cyclists drive at their own preferred speed. Pass other, slower cyclists if necessary.	A large part of the mopeds drives much faster than 30 km/h. The speed does not depend on the profile or the number of speed bumps.
Traffic volume	*Intended behaviour*	Only local traffic with its origin or destination in the direct neighbourhood of the bicycle street.	A large volume of through-going cyclists should be present at the street.	Only local traffic with its origin or destination in the direct neighbourhood of the bicycle street.	Only local traffic with its origin or destination in the direct neighbourhood of the bicycle street.	A large volume of through-going cyclists should be present at the street.	Only local traffic with its origin or destination in the direct neighbourhood of the bicycle street.
	Observed behaviour	On two bicycle streets is through-going motorized traffic present at bicycle street. Driving behaviour differs from local traffic: higher speed, tendency to pass cyclists.	Large volumes of through-going cyclists are present at all bicycle streets.	Volume of mopeds differs from bicycle street to bicycle street. In all cases are through-going mopeds present at the bicycle street.	Bicycle streets are only used by local traffic. Traffic volume depends on the size of the residential area and the number of streets connected to the bicycle street.	Large volumes of through-going cyclists are present at all bicycle streets.	Small volumes of mopeds on the bicycle street, main part is through-going traffic.

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5 BICYCLE STREETS AND SUSTAINABLE SAFETY

The Dutch traffic safety vision Sustainable Safety is applied in the Netherlands since the mid nineties of the last century. The Sustainable Safety vision is based on five principles, shown in Table 10 together with a short description per principle.

TABLE 10: SUSTAINABLE SAFETY PRINCIPLES (SWOV, 2010E)

Sustainable Safety Principle	Description
***Functionality* of roads**	Monofunctionality of roads as either through roads, distributor roads, or access roads in a hierarchically structured road network
***Homogeneity* of mass and/or speed and direction**	Equality of speed, direction and mass at moderate and high speeds
***Predictability* of road course and road user behaviour by a recognizable road design**	Road environment and road user behaviour that support road user expectations through consistency and continuity of road design
***Forgivingness* of the environment and of road users**	Injury limitation through a forgiving road environment and anticipation of road user behaviour
***State awareness* by the road user**	Ability to assess one's capacity to handle the driving task

The first three principles focus at the infrastructure, while the last two principles cover the road user and its behaviour. The application of bicycle streets in the Netherlands was analysed considering the three principles focussing on infrastructure. The fourth principle, forgivingness, was analysed while only considering the forgivingness of the environment of the bicycle street.

The analysis of the bicycle street on the Sustainable Safety principles is based on the results of the functional analysis and the empirical research into the driving behaviour and usage of the bicycle street.

5.1 FUNCTIONALITY

Roads should only have one function in a hierarchically structured road network (SWOV, 2010c). This monofunctionality is not the case on bicycle streets, since bicycle streets have different functions in different networks.

In the car network, a bicycle street has an access function, providing access to the parcels along the street. Since only traffic with its origin or destination in the direct neighbourhood of the street should use the street, the traffic flow of motorized vehicles is limited. Since the bicycle street has an access function, there will be a lot of exchanging traffic on the bicycle street.

In the bicycle network, a bicycle street has both an access and a flow function. The bicycle street provides access by bike to the parcels along the street, but is at the same time part of a main bicycle route. Those three functions of bicycle streets are conflicting with each other and are therefore a threat for the traffic safety.

Based on the observations could be concluded that especially the mix of the flow function of cyclists and the access function of cars leads to conflicts. Vehicles stopping or turning on the bicycle street create possible conflict situations between cyclists and cars on the bicycle street. Due to the fact that the bicycle street is part of a main bicycle route, a large volume of cyclists is using the bicycle street. The chance that there occurs a conflict between a stopping or turning vehicle and a cyclist on the bicycle street is therefore large.

Since through-going cyclists on the bicycle street will try to pass a vehicle blocking the bicycle street as fast as possible, conflicts could occur on the bicycle street. Traffic in the opposite direction will not always anticipate on cyclists passing the vehicle blocking the bicycle street.

Because the bicycle street has an access function, cars will be parked along the street or depart from a parking spot. Since the bicycle intensities are high at bicycle streets, a parking car will often conflict with cyclists on the bicycle street. Further, opened doors of parked vehicles are conflicting with cyclists on the bicycle street, especially since some cyclists are using the rabat strip.

5.2 Homogeneity

The differences in the kinetic energy of the crash partners should be small to reduce the impact of the crash. Therefore there should be a homogeneity in mass and direction at moderate and high speeds, or a low speed when direction and mass are not homogeneous (SWOV, 2010a). In the case of a bicycle street, motorized and non-motorized vehicles are mixed at the same street, so there will be a large difference in mass. The driving directions are not separated. In the case of a two-lane bicycle street is the median often more a visual separation than a physical separation between the carriageways.

Since different masses and directions are mixed on one street, speeds should be low to reduce the crash impact. A speed of 30 km/h or lower could be considered as a safe speed, because the chance of surviving a crash with a motorized vehicle as a pedestrian is large. When the speed increases, the chance of surviving a crash as a pedestrian decreases dramatically (Wegman & Aarts, 2005). Since cyclists are also considered as vulnerable road users, the chance of surviving a crash as a cyclists will decrease when the speed of motorized vehicles increases.

The speeds of motorized vehicles on the bicycle street have been studied in this research. The results of this study show that on most bicycle streets, the mean speeds are 30 km/h or lower. However, mean speeds do not always give a good representation of the speed on the bicycle street, because a slow and a fast vehicle could give the same mean speed as two vehicles driving at the same speed. Therefore, the V85-value has also been calculated. This value gives the speed that is not exceeded by 85% of the vehicles passing. This is a good indication to see whether a speed limit on a street is credible ("Wat is V85?", 2013) On average, this V85-value lies around 37 km/h for the studied bicycle streets. This is quite high compared with the speed limit of 30 km/h at the bicycle streets. So, road users do not consider 30 km/h as a credible speed on most of the bicycle streets. The speeds per street depend for an important part on the profile and dimensions of the bicycle street.

The speeds of motorized vehicles are quite high considering the 30 km/h speed limit. One could conclude that the road users do not consider 30 km/h as a credible speed limit. The design should be adjusted to make the speed limit of 30 km/h credible. Possible measurements could be a narrower profile or the application of speed bumps.

The speeds of mopeds could be derived in two groups: one group of speeds around 20 km/h, mostly slow mopeds probably, and one group with speeds of 40 km/h. The mean speeds of mopeds on bicycle streets lie around 30 km/h, but the V85-values lie around the 45 km/h. The large difference between the mean speed and the V85-value is caused by a large group of mopeds driving too fast on the bicycle street. This fast driving group is a threat for the traffic safety on the bicycle street.

5.3 Predictability

A predictable road helps the road user to easy understand what the expected behaviour is and what behaviour could be expected from other road users. The expected behaviour is captured in the mental profile associated with the design elements of the bicycle street (Harms & Dicke-Ogenia, 2011).

Since one standard lay-out is missing and the bicycle streets differ per lay-out, road users create a new mental profile per bicycle street. This makes it hard for road users to understand which behaviour is expected and what behaviour could be expected from other road users.

To improve the predictability of traffic on the bicycle street, the special position of cyclists on bicycle streets should be recognisable. This could be done by applying red-coloured asphalt on the bicycle street, because red-coloured asphalt will be associated with cyclists. Although the application of red-coloured asphalt for bicycle streets seems obvious, this is not always the case as can be seen in Figure 19 and Figure 20.

FIGURE 19: YELLOW BICYCLE STREET IN VLISSINGEN (SOURCE: DICHTERBIJDEZEE.BLOGSPOT.NL)

FIGURE 20: BLACK BICYCLE STREET IN VLAARDINGEN (SOURCE: DEWEEKKRANT.NL)

Variants like shown in Figure 19 and Figure 20 do not contribute to the recognisability of bicycle streets in the Netherlands. In those variants it is not even clear that cyclists are the main users of the street. But even when red-coloured asphalt is used, the bicycle street and the central position of cyclists on the street are not always recognizable. Figure 21 and Figure 22 show both bicycle streets with red-coloured asphalt, but both streets differ strongly from each other in the design principles that are used. The wide profile of the bicycle street in Figure 21 will be probably associated with a normal road while the narrower profile of the bicycle street in Figure 22 has dimensions comparable with the dimensions of bicycle paths. On the first bicycle street, cyclists will stay on the right-hand side, while at the second bicycle street, cyclists will move to the middle of the street due to the design of the bicycle street.

FIGURE 21: A TWO-LANE BICYCLE STREET WITH A WIDE PROFILE WHERE CYCLISTS CHOOSE TO DRIVE ON THE RIGHT-HAND SIDE OF THE ROAD.

FIGURE 22: A NARROW SINGLE-LANE BICYCLE STREET, WHERE THE CAR HAS TO STAY BEHIND THE CYCLIST SINCE THERE IS NO SPACE TO PASS THE CYCLISTS.

Even when the same type of bicycle street lay-outs is considered, essential differences could be found. Those differences could be found in the dimensions of the rabat strip, driving strip and distance from house front to house front. Also the type of elements used for the rabat strip and the traffic signs for the bicycle street, vary per bicycle street.

In Figure 23 and Figure 24, two different single-lane bicycle streets are shown. In Figure 23, the bicycle street has lane lines in the middle of the street to divide the two driving directions and emphasize the bicycle path character of the street. There has been chosen for a blue rectangular traffic sign, with a white cyclist in front of a red car. This traffic sign should tell the road users that the cyclists are the main users of the street and cars should not pass the cyclists in principle. Figure 24 shows a bicycle street with the same type of lay-out. This bicycle street does not have lane lines in the middle of the street. Furthermore, there has been chosen for another traffic sign. The chosen traffic sign is red, with a yellow bicycle on it. The bicycle has a crown, to show that the cyclists are the king or queen of the street and other users should bow for them.

FIGURE 23: BICYCLE STREET WITH LANE LINES IN THE MIDDLE OF THE STREET AND A BLUE TRAFFIC SIGN. THIS BICYCLE STREET DIFFERS FROM OTHER SINGLE-LANE BICYCLE STREETS, BECAUSE ON THIS BICYCLE STREET A LANE LINE HAS BEEN APPLIED.

FIGURE 24: BICYCLE STREET WITHOUT LANE LINES AND WITH A RED TRAFFIC SIGN. THIS BICYCLE STREET DIFFERS FROM OTHER SINGLE-LANE BICYCLE STREETS, BECAUSE HERE A SUBSTANDARD TRAFFIC SIGN HAS BEEN APPLIED.

It could be concluded that there is a large variation in design features of bicycle streets. There is no general traffic sign and even the red-coloured asphalt is not a standard. Those factors do not positively contribute to the recognisability of the bicycle street and the creation of a mental profile by road users. The lack of one clear and recognisable design with one standard traffic sign does also not contribute to a predictable road course and road user behaviour.

5.4 Forgivingness

The Sustainable Safety principle 'forgivingness' states that mistakes of traffic participants should be forgiven by the environment of the road and the other road users (SWOV, 2010c). The presence of this principle at bicycle streets is considered. This principle could be split up in two parts: a social and a physical part. The social part includes that traffic participants will forgive the mistakes of other traffic participants and give them space to correct their mistakes. The physical part states that the infrastructure should provide space to road users to correct their mistakes or to reduce the impact of a mistake, for example an obstacle free road side.

At single-lane bicycle streets, the main driving strip is the red-coloured asphalt layer in the middle of the street. The rabat strips on both sides of this driving strip provide extra space for cars. However, those rabat strips provide also extra space for cyclists to correct a mistake of their own or to avoid a mistake of another road user.

The rabat strip provides also a safety zone between the parking spots and the driving strip. Car drivers opening their door without having a look at the traffic on the bicycle street are forgiven by the extra space between the parked car and the driving strip. However, the rabat strip is sometimes too small, so the doors also reach the driving strip. Furthermore, the rabat strip is used by some cyclists, not anticipating on doors of parked cars opening just in front of them.

In case of a two-lane bicycle street, no rabat strip is present at the street. However, this type of bicycle streets has a wider profile than the single-lane bicycle streets of the street. Due to this wider profile, there is extra space available to forgive mistakes of other road users. Since cars and cyclists drive at the right-hand side of the street, there is no space available for cyclists to avoid mistakes of other road users by moving to the right. The median provides only extra space for cars to avoid mistakes of cyclists. The edge of the sidewalk along the bicycle street could be an obstacle for cyclists on the bicycle street.

On some of the bicycle streets, cuts for motorized traffic have been applied. Those cuts contain often a pole in the middle of the driving strip. Those poles are not crash-friendly and a real hazard for cyclists. The application of soft poles or another obstacle for motorized vehicles is therefore recommended.

Since bicycle streets are not monofunctional, they could be considered as 'grey roads'. On this type of roads, the access and flow functions are mixed. This mix leads to conflicts and unsafety on the road since the directions and speeds could differ strongly. The Sustainable Safety principle ‘forgivingness’ helps traffic engineers to make a practical choice between both functions (Dijkstra, Eenink & Wegman, 2007). So conflicts will occur due to the mix of functions and cannot be prevented since it is hard to separate the functions. However, by designing forgiving infrastructure the effects of those conflicts could be reduced. Forgiving infrastructure provides for example extra space to avoid conflicts or crash-friendly obstacles along the road side. Single-lane bicycle streets provide this extra space by introducing the rabat strips, while the two-lane bicycle streets provide extra space in the middle of the road.

The conclusion is that rabat strips along single-lane bicycle streets of the street provide space for the correction of one's own mistakes and the avoidance of another one's mistakes. This is especially the case for cyclists, since cars are already using the rabat strips under normal conditions. At two-lane bicycle streets, the median provides extra space for cars to avoid mistakes of cyclists.

5.5 Conclusions

Bicycle streets do not meet the principles of Sustainable Safety. The main principle of a bicycle street, creation of a main bicycle route through a residential area, does not comply with the monofunctionality principle of Sustainable Safety. In practice, conflicts have been observed due to the combination of the access function for cars and the flow function for cyclists. Stopping and parking cars conflicting with cyclists on the bicycle street are an example of the effects of this mix of functions. Those conflicts could only be prevented by separating those functions completely. The design could be adjusted to mitigate the effects of the conflicts.

Traffic is not separated by direction or mass at the bicycle streets, so to create a homogeneous traffic flow speeds should be low. At most bicycle streets, the speeds of motorized vehicles and mopeds are too high. The speeds of motorized vehicles depend for an important part on the profile of the bicycle street. The high speeds of mopeds are a threat for traffic safety, but are not only a problem on bicycle streets. Especially young drivers tend to drive at high speeds (SWOV, 2009).

Large improvements could be made considering the predictability of the road course and road users. Since there is a wide variation in designs and traffic signs that are applied in the Netherlands, bicycle streets are not very recognisable for road users. The traffic behaviour at the bicycle streets is therefore not always predictable. By applying one standard lay-out, associated with the mental profile of a bicycle path, and one standard traffic sign, bicycle streets should become recognisable. This will help in the growth of a mental profile and improves the predictability of the road course and the driving behaviour of other road users.

The environment of single-lane bicycle streets is forgiving to cyclists on the bicycle street. The rabat strips along the driving strip provide extra space for cyclists to avoid mistakes of other road users and to correct their own mistakes. The application of rabat strips along the street provides an extra obstacle free space between the road side and cyclists cycling on the driving strip. Two-lane bicycle streets have extra space available in the middle of the street, that can be used by cars to avoid mistakes of cyclists but will not be used the other way around.

6 DESIGN

Based on the conclusions of the previous chapters studying the function of and driving behaviour at bicycle streets, the designs of the studied bicycle streets are reviewed. In this chapter, one statement is tested: 'differences between the intended and the observed behaviour are related to the design of the bicycle street'. Those differences have been described in section 4.7. The behaviour as intended by the traffic engineers designing the bicycle streets is considered as safe behaviour. The behaviour observed on the bicycle streets could differ from this intended behaviour. Those differences could lead to conflicts and unsafe situations on the bicycle street. It could therefore be useful to adjust the design, in order to improve the traffic safety.

The differences between the intended and observed behaviour are already described in the conclusions of chapter 4. In chapter 5, the designs of bicycle streets have been tested to the Sustainable Safety principles. The conclusions drawn in section 4.7 and 5.5 are the base for the design improvements that are proposed in this chapter. Furthermore, the conclusions about the functions of bicycle streets have been used to determine possible conflicts due to the mix of functions on the bicycle streets. The design improvements aim on a safer mix of functions on the bicycle street instead of separating the functions. Separating the functions should affect the main benefit of a bicycle street, creating a high quality bicycle amenity within the limited available space in a residential area, too much.

The guidelines available in the Design manual for bicycle traffic (CROW, 2007) and the ASVV 2012 (CROW, 2012) were reviewed in the second section, based on the results of the previous chapters. The dimensions of the cross-sectional profile of the bicycle street and the other recommendations regarding the design of bicycle streets that are advised by those guidelines are reviewed.

Recommendations for the improvement of the design of bicycle streets are made in the last section of this chapter. The recommendations are related to the design of road sections and intersections. Considering the road sections, attention is paid to the dimensions of the profile and parking along the bicycle street. Regarding the intersections between the bicycle street and crossing access roads, recommendations are made about the horizontal design of the intersection, the priority regulation and the traffic sign. Finally, the existing guidelines as present in the Design manual for bicycle traffic were adjusted and new guidelines were added. The guidelines provide information for traffic engineers designing bicycle streets.

6.1 EVALUATION OF THE EXISTING DESIGNS

The designs of the studied bicycle streets are evaluated per type of bicycle street. This is done based on the conclusions on intended and observed behaviour in Table 9. It could be concluded that the observed and intended behaviour of single-lane bicycle streets lie closer to each other than the observed and intended behaviour of two-lane bicycle streets.

So is the observed position on the road of cyclists and motorized vehicles as intended on single-lane bicycle streets, but not on two-lane bicycle streets. These results in higher speeds on two-lane bicycle streets, in comparison to single-lane bicycle streets. On both types of bicycle streets a large part of the mopeds and motorized vehicles drives faster than intended.

The bicycle streets in the Netherlands have further been tested to the principles of Sustainable Safety. The most important conclusion of the test to the Sustainable Safety principles is that bicycle streets are not recognisable for road users. For many road users it is not clear that they are driving on a bicycle street, but the design makes also not clear what behaviour is expected and could be expected on the street. To improve the recognisability of bicycle streets and the predictability of the road course and the driving behaviour of road users, there should be one clear design standard. Since the observed behaviour on single-lane bicycle streets lies closer to the intended behaviour than on two-lane bicycle streets, it could be concluded that the single-lane bicycle street contains design elements that are associated with the mental profiles containing the intended behaviour. So will the narrow red-coloured driving strip be associated with a bicycle path. Possible improvements could be to add bicycle path lane lines in the middle of the street to improve the recognisability. The function of the rabat strip is not clear to all cyclists. This could be improved by integrating the rabat strip with the gutter and strengthen the association with the gutter for cyclists.

Based on the principle of homogeneity could be concluded that the single-lane bicycle street is the best choice as base for an improved design. Cyclists are more prominent in the view of car drivers and cars have to adjust their speed to the speed of cyclists. Due to the small profile, speeds are also low when there are not that many cyclists. The position of cyclists on two-lane bicycle streets is less prominent, the speeds are higher and depend for an important part on the number of cyclists on the street. But also on single-lane bicycle streets, a large part of the motorized vehicles drives too fast. In the adjusted design, attention should be paid to the speed choice of motorized vehicles on the bicycle street. Furthermore should be tried to lower the speeds of mopeds on the bicycle street, since mopeds drive much too fast on the bicycle streets. Possible solutions are a narrower profile and the application of speed bumps on the bicycle street.

Furthermore, based on the principle of forgivingness could be concluded that the one-lane bicycle street is again the best choice. The rabat strips along the asphalt driving strip provide space for cyclists to correct their own mistakes and to avoid mistakes of other road users on the bicycle street.

The Sustainable Safety principle 'functionality' does not differ per type of bicycle street. On both types, the flow function of cyclists and the access function for motorized vehicles are conflicting. This conflict is the base of bicycle streets and can only be prevented by the realisation of bicycle paths separated from access roads. However, within existing urban areas, often no space is available for the realisation of separate bicycle paths and bicycle streets are a compromise in facilitating large volumes of bicycle traffic. The conflicts that occur are mainly conflicts between cyclists flowing on the bicycle street and motorized vehicles stopping on the carriageway for supply of parcels along the road or vehicles parking along the carriageway. In the design will be tried to mitigate these conflicts or prevent them by forms of regulation.

Based on the evaluation of the designs could be concluded that the traffic safety of bicycle streets can be improved. The first step is to apply only one type of bicycle streets. It could be concluded that the single-lane bicycle street is the best choice. The second step is to adjust this design to improve the design of this bicycle street design further.

6.2 Guidelines

Guidelines for the design of bicycle streets are provided by CROW-publication 216/Fietsberaad publication 6, bicycle streets in main bicycle routes (Andriesse & Ligtermoet, 2005), the design manual for bicycle traffic (CROW, 2007) and the ASVV 2012 (CROW, 2012). The guidelines in the ASVV 2012 are copied from the guidelines in the design manual for bicycle traffic. CROW-publication 216 does provide guidelines for the choice of a bicycle street design at a certain street, while the design manual for bicycle traffic provides guidelines for the dimensions of the cross-sectional profile of a bicycle street.

The design manual for bicycle traffic provides dimensions for three types of bicycle streets: a mixed profile, a single-lane bicycle street and a bicycle street with two wide bicycle lanes. Dimensions for a two-lane bicycle street are not given in the design manual. Therefore, only the design guidelines for a single-lane bicycle street are reviewed.

According to the design manual for bicycle traffic (CROW, 2007), a single-lane bicycle street should be applied on an access road, as part of a main bicycle route. The volume of cyclists at the street is at least twice as large as the volume of cars. The volume of cars should be smaller than 2000 vehicles per day. Single-lane bicycle streets should only be applied on one-directional streets for cars.

The studied single-lane bicycle streets are tested to the guidelines provided by the design manual for bicycle traffic. The studied single-lane bicycle streets are all access roads and part of a main bicycle route. Only at two of the four studied single-lane bicycle streets, the volume of cyclists is twice as large as the volume of cars. On all the single-lane bicycle streets, the volume of cars is smaller than the 2000 vehicles per day. All the single-lane bicycle streets that have been studied were bidirectional streets.

Based on the study of the driving behaviour could be concluded that the volume of cyclists should not necessarily be twice as large as the volume of cars. To dominant position of cyclists on the bicycle street becomes already clear when the volume of cyclists is as high as the volume of cars. The single-lane bicycle street design could perfectly be applied on bidirectional streets. No conflicts have been observed due to the fact that cars drive in both directions.

The dimensions given by the design manual are a width of the carriageway of 4.50 metres, a width of the rabat strips of 0.75 metres each and a width of the driving strip of 3.00 metres. The studied single-lane bicycle streets all have a carriageway with a width of around 4.50 metres. The width of the driving strip and rabat strip vary per street. On streets with a wider rabat strip and a smaller driving strip, more cyclists tend to drive on the rabat strip instead of the driving strip. The width of the rabat strip advised by the design manual is quite large.

6.3 Design recommendations

The evaluation of the bicycle streets shows that the largest problem is the recognisability of bicycle streets by road users. This problem is caused by two factors: there are not that many bicycle streets in the Netherlands, so a large part of the road users is not confronted with a bicycle street design and the bicycle streets that are present in the Netherlands have often different designs and traffic signs. Since the number of bicycle streets will grow slowly, the recognisability should be improved by the application of one clear design standard on all bicycle streets. Further could the application of recognisable design elements help to create the desired driving behaviour. Based on the evaluation of the studied bicycle street designs, the single-lane bicycle street design is preferred to the two-lane bicycle street design. Therefore, as one standard design for bicycle streets the single-lane bicycle street is proposed.

The profile of the bicycle street plays an important role in the speed choice of car drivers on the bicycle street. Therefore the dimensions of the cross-sectional profile are studied. The results of the study of the driving behaviour on bicycle streets show that cars drive faster on a bicycle street with a wider profile. The width of the driving strip influences the speed of cars a bit, but influences also the speeds of cyclists. Cyclists having more space, will hinder each other less and drive faster. Less hinder will increase the comfort of cycling on the bicycle street.

The design manual for bicycle traffic (CROW, 2007) advises as dimension for a solo bidirectional bicycle path a width of 4.00 metres if during peak hour more than 100 cyclists pass. This is the case at all the studied bicycle streets, so this width will be taken as a starting point for the width of the driving strip at the bicycle street.

Since cars in two directions are using the bicycle street, the width of the street should be wide enough for two cars passing each other in the opposite direction. For a car, an average width of 1.75 metres has been assumed with 0.25 metres of free space on both sides of the car (CROW, 2012) The total design width is 2.25 metres per car. Two cars passing each other will require a width of 4.50 metres. Compared with the 4.00 metres for the driving strip, an extra width of 0.50 metres is needed. This extra width will be created by two rabat strips with a width of 0.25 metres each. This profile is shown in Figure 25.

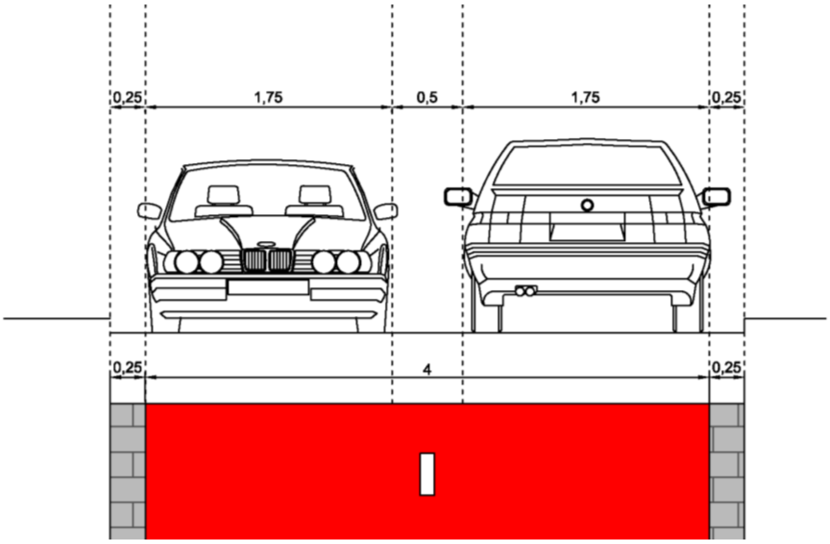


FIGURE 25: CROSS-SECTIONAL PROFILE OF SINGLE-LANE BICYCLE STREET BASED ON THE DIMENSIONS OF A SOLO BIDIRECTIONAL BICYCLE PATH (DIMENSIONS IN METRES). TWO CYCLISTS CAN COMFORTABLE DRIVE NEXT TO EACH OTHER ON THIS STREET, BUT CARS WILL NOT DRIVE ON THE RABAT STRIP.

In Figure 25 can be seen that cars will probably not use the rabat strip, but drive with four wheels on the asphalt layer. The disadvantage will be that the profile looks wider and cyclists will be less prominent in the view of the car driver, since cyclists will drive at the right-hand side of the driving strip. By enlarging the width of the rabat strip, the profile will look narrower and cyclists will move more to the middle of the street. Their position will be more prominent in the view of the car driver and the speed of cars will be lower. Therefore, the width of the rabat strip is doubled in the profile in Figure 26.

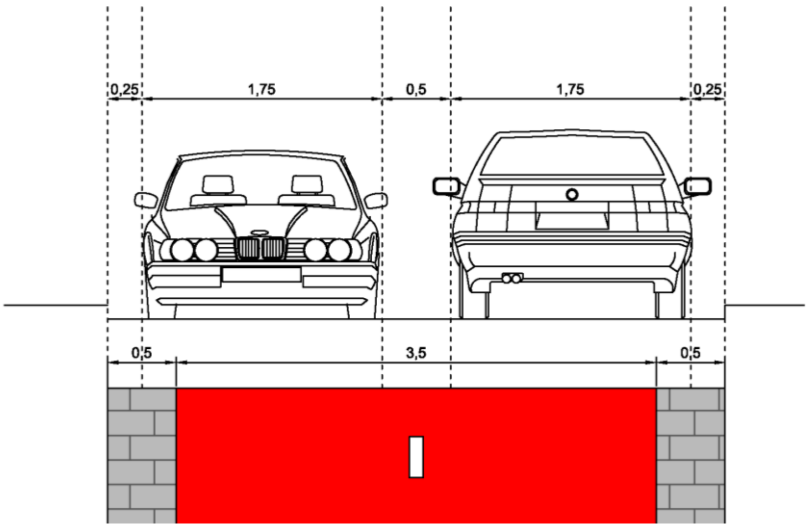


FIGURE 26: CROSS-SECTIONAL PROFILE OF SINGLE-LANE BICYCLE STREET WITH WIDER RABAT STRIPS (DIMENSIONS IN METRES). IN THIS PROFILE, CARS WILL HAVE TO USE THE RABAT STRIPS. THIS CONTRIBUTES TO LOWER SPEEDS OF CARS ON THE BICYCLE STREET. THE WIDTH OF THE DRIVING STRIP IS STILL COMFORTABLE FOR CYCLISTS ON THE BICYCLE STREET.

By making the driving strip narrower, cyclists will probably not move more to the middle to the street, but more cyclists will use the rabat strip instead. A driving strip with a width of 3.5 metres provides a comfortable bicycle path to cyclists and a narrow profile to cars.

It could be the case that not the passing of two cars is normative for the dimensions, but the width of a truck and a car passing each other. If this is the case depends on the probability that a truck and a car meet each other on the bicycle street. This probability will be larger when the length of the bicycle street is long or many trucks are using the bicycle street for example for supply of shops along the bicycle street. The width of the profile will become larger and the speed will increase. In Figure 27, the profile of a bicycle street dimensioned on a truck and a car passing each other is shown. This profile has a width of 5.0 metres, because both rabat strips are 0.25 metres wider.

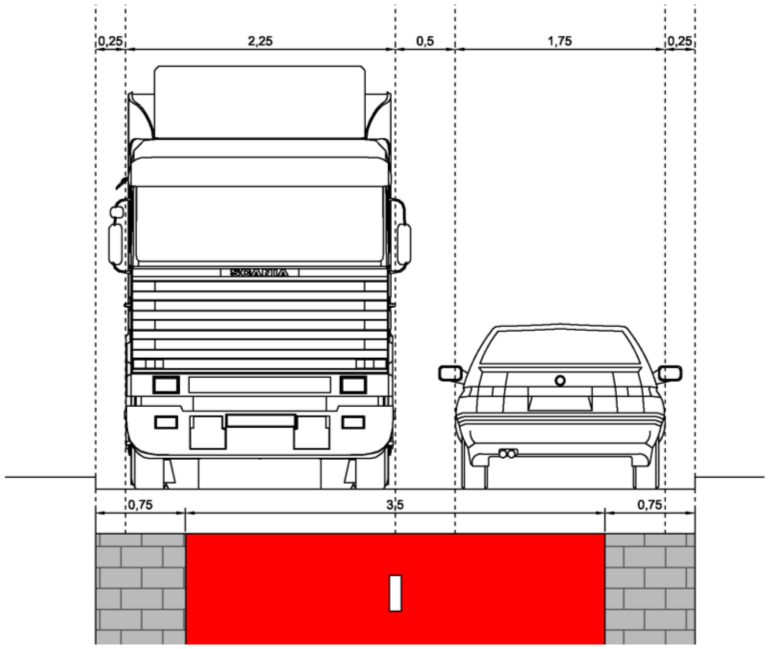


FIGURE 27: CROSS-SECTIONAL PROFILE DIMENSIONED ON THE WIDTH OF A TRUCK AND A CAR PASSING EACH OTHER (DIMENSIONS IN METRES). THE EXTRA WIDTH NEEDED FOR THE TRUCK IS ADDED TO THE RABAT STRIPS ALONG THE SIDES.

If the volume of truck traffic on the bicycle street is large, the width of two trucks should be leading for the dimensions of the profile. The width will become 5.5 metres, see Figure 28, one metre wider than the first profile based on two cars passing. In this profile, two passing cars will have 0.5 metres more space per car. This extra space will lead to an increase of the speed of the cars on the bicycle street. The extra space in the profile is illustrated in Figure 29, showing two passing cars within the dimensions of the trucks. If the volume of truck traffic is that high that the profile should be dimensioned on two passing trucks, one should critically review the choice for a bicycle street on that location. The high car speeds due to the wide profile and the large volume of trucks on the bicycle street do not contribute to a safe and attractive bicycle route.

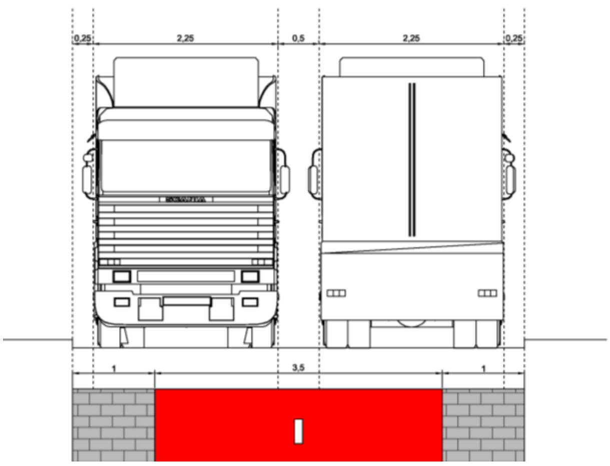


FIGURE 28: CROSS-SECTIONAL PROFILE BASED ON THE WIDTH OF TWO PASSING TRUCKS. THIS PROFILE BECOMES REALLY WIDE WITH A TOTAL WIDTH OF 5.5 METERS.

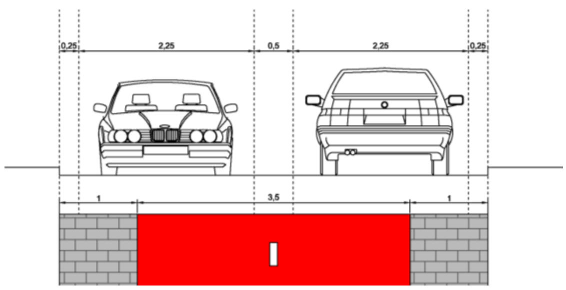


FIGURE 29: TWO PASSING CARS ON A SINGLE-LANE BICYCLE STREET WITH A WIDE PROFILE. CARS CAN PASS EACH OTHER WITH A LARGE SPACE BETWEEN THEM. THEIR SPEEDS ARE THEREFORE EXPECTED TO BE RATHER HIGH.

Summarized, the optimal profile is the profile with the minimum width. A normal bicycle street should have a profile with a width of 4.50 metres. Only when the probability of a truck and a car meeting each other on the bicycle street is large because of truck generating activities along or in the neighbourhood of the bicycle street, a profile of 5.0 metres can be applied. A bicycle street should not have a profile wider than 5.0 metres, since the bicycle street will be too wide and speeds will be too high. If for some reason a profile wider than 5.0 metres is needed, the application of a bicycle street should be reconsidered.

The study of the driven speeds on the bicycle streets shows that on the single-lane bicycle streets in Oss and Zwolle, quite a large part of the motorized vehicles drives faster than 30 km/h. On the single-lane bicycle streets in Haarlem and Houten, this volume of motorized vehicles driving faster than 30 km/h on the bicycle street is much lower. Since the profiles of the four single-lane bicycle streets are comparable, a possible explanation for this difference can be found in the application of speed bumps on the bicycle streets. In Haarlem and Houten, speed bumps are applied, while in Oss and Zwolle no speed bumps are present on the bicycle street. It is therefore advisable to apply speed bumps on the bicycle street, although speed bumps decrease the comfort for cycling on the bicycle street.

During the observations has been noticed that on intersections where the priority of traffic on the bicycle street is regulated by an exit construction, traffic on the crossing street gives always priority to the traffic on the bicycle street. On intersections where the priority only was regulated by shark's teeth and traffic signs, not all the traffic on the crossing street gave priority to the bicycle street. Those observations could be combined with the conclusion that speed bumps do contribute to lower speeds of motorized vehicles on the bicycle street by the application of raised intersections on the bicycle street.

Those raised intersections will lower the speeds driven on the bicycle street by mopeds and motorized vehicles and will at the same time lower the speeds of traffic on the crossing street when crossing the bicycle street. On the raised intersection, the rabat strip and red driving strip on the bicycle street should continue to emphasize the bicycle street for traffic on the crossing street. Priority should be regulated by shark's teeth and traffic signs on the intersection. This type of intersections is already applied on the bicycle street in Houten. Figure 30 shows the sketch design of a raised intersection in a bicycle street. The rabat strip will diverge till the speed bumps in the crossing streets. This is done to emphasize the crossing of the bicycle street.

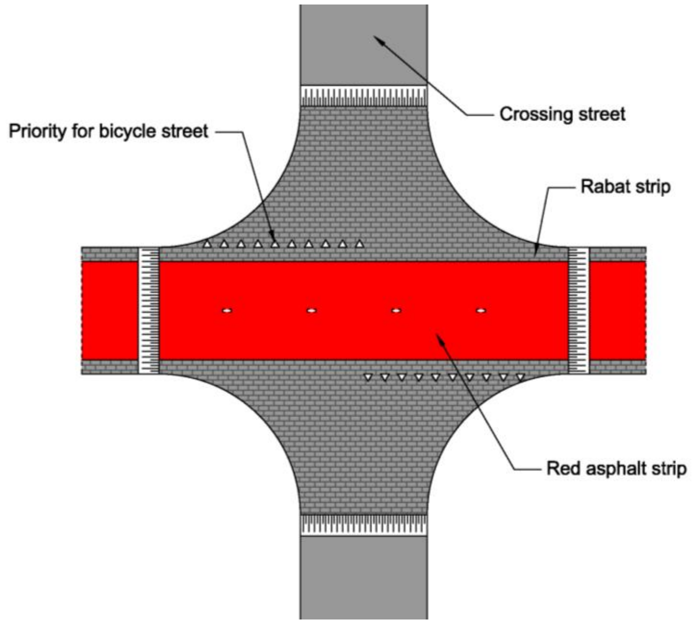


FIGURE 30: SKETCH DESIGN OF A RAISED INTERSECTION BETWEEN A BICYCLE STREET AND A CROSSING ACCESS ROAD. THE RED DRIVING STRIP CONTINUES ON THE INTERSECTION AND PRIORITY IS REGULATED BY SHARK'S TEETH.

Besides the application of only one design for bicycle streets, the recognisability of bicycle streets could be further improved with two relatively simple measures. The first measure is the application of a lane line in the middle of the street. This lane line should be the same as the lane line on bicycle paths. The length dimensions of the lane lines are 30 centimetre paint and 270 cm asphalt. The width of the lane line should be 10 cm (CROW, 2007). Those dimensions are illustrated in Figure 31.

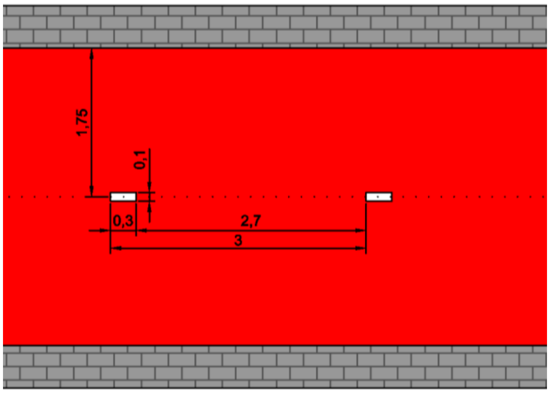


FIGURE 31: DIMENSIONS OF LANE LINES ON SINGLE-LANE BICYCLE STREET (DIMENSIONS IN METRES). THOSE DIMENSIONS ARE THE SAME AS PROVIDED BY THE DESIGN MANUAL FOR BICYCLE TRAFFIC (CROW, 2007).

Furthermore, the recognisability of bicycle streets could be improved by applying one standard traffic sign on all bicycle streets in the Netherlands. This traffic sign should make clear for cars that they are using a bicycle facility and therefore should anticipate on cyclists on the street. This traffic sign should also make clear for cyclists that they are cycling on a bicycle street instead of a bicycle path and therefore should expect cars.

In the evaluation of the bicycle street in Haarlem (Pau Kho, 2006), the survey group was asked which traffic sign should be used to make clear that the street is a bicycle street. 59 percent of the respondents preferred the traffic sign, shown in Figure 32.

This traffic sign shows that cyclists and cars share the same space. The red-coloured car shows that the cyclists is the main user of the street. The Belgian government has chosen this traffic sign as the official traffic sign for bicycle streets in Belgium ("De fietsstraat officieel in België", 2013). In the Netherlands, this traffic sign does not have an official status with behavioural rules attached to it.

Another traffic sign that is used at many bicycle streets is shown in Figure 33. The traffic sign for a bicycle path is the base of this traffic sign. To this traffic sign is added with text and symbols that it is not a bicycle path, but a bicycle street and that therefore motorized vehicles and mopeds are allowed. This traffic sign meets therefore the earlier recommendation that a bicycle street should be associated with a bicycle path the best.

FIGURE 32: THE MOST PREFERRED TRAFFIC SIGN FOR BICYCLE STREETS BY RESPONDENTS ON THE EVALUATION OF KHO (2006)

FIGURE 33: THE SECOND MOST PREFERRED TRAFFIC SIGN IN THE EVALUATION OF KHO (2006)

Not only the predictability and homogeneity of traffic on the bicycle street could be improved. Since on a bicycle street different functions are mixed, conflicts have been observed related to this mix of functions. Conflicts occur between the access function for cars and the flow function for a large part of the cyclists. Cars stop at the carriageway and block therefore the carriageway for flowing cyclists. Cyclists avoiding the stopped car are mixing with the opposite direction or using the sidewalk. Cars should not stop on the bicycle street, this should be regulated by a stopping prohibition on the bicycle street.

Other conflicts related to this mix of functions have been observed between vehicles parking along the bicycle street and flowing cyclists. Especially between the opened doors of parked cars and cyclists on the bicycle street conflicts occur. In CROW-publication 216/Fietsberaad publication 6 (Andriesse & Ligtermoet, 2005) is stated that the rabat strip can be used as a safety zone between the parking spots along the bicycle street and the cyclists driving on the asphalt driving strip. This double use of the rabat strip saves space at the bicycle street.

However, this double use leads to conflicts, because observations show that large groups of cyclists are using the rabat strip as an extra space. Also solo cyclists are using the rabat strip since it is possible to use the rabat strip over the full length of the bicycle street. Opened doors of cars block the whole rabat strip and are an obstacle for cyclists on the rabat strip. It is therefore recommended to apply an extra safety zone between the rabat strip and the parking spot. By only applying this safety zone at the location of the parking spots, cyclists will not use this safety zone. In Figure 34, the dimensions of parking spots along the bicycle street with an additional safety zone are given.

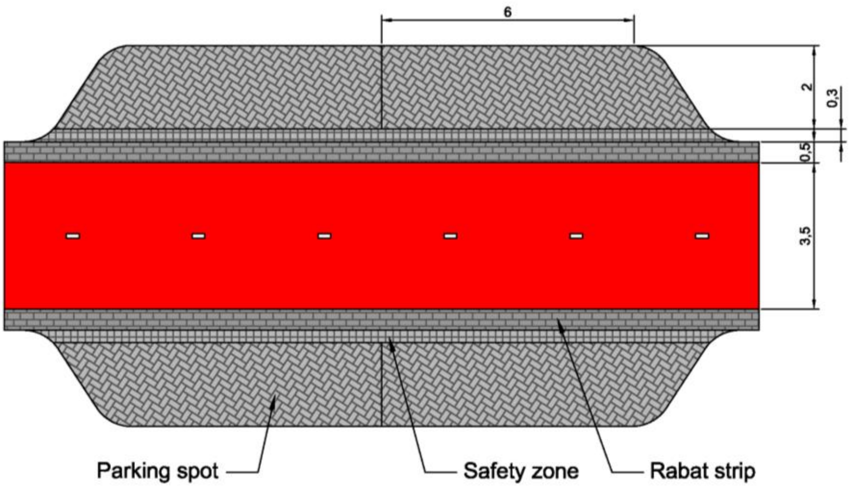


FIGURE 34: PARKING SPOTS ALONG BICYCLE STREET WITH ADDITIONAL SAFETY ZONE (DIMENSIONS IN METRES). THE SAFETY ZONE IS ONLY PRESENT ALONG PARKING SPOTS, WHILE THE RABAT STRIP CONTINUES ALONG THE WHOLE BICYCLE STREET. CYCLISTS WILL THEREFORE NOT USE THE SAFETY ZONE, WHILE THE RABAT STRIP IS USED BY SOME OF THE CYCLISTS.

The recommendations made in this chapter will contribute to an improvement of the traffic safety of bicycle streets. Those recommendations are related to the guidelines that are present in the Design manual for bicycle traffic (CROW, 2007). The guidelines are adjusted based on the recommendations that are made in this chapter. The adjusted guidelines are given in Table 11. Important changes compared with the guidelines in the Design manual for bicycle traffic are discussed below.

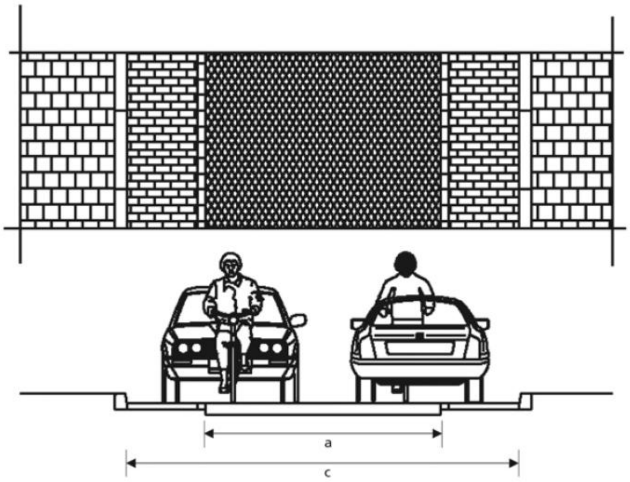
The most important change considering the application of bicycle streets is that there should be more cyclists than cars, but not necessary more than twice as much cyclists than cars on the bicycle street. More important is the volume of cyclists on the bicycle street. If the volume of cyclists is larger than 1000 cyclist per day, about 100 cyclists will be cycling on the bicycle street during the peak hour. This means more than one cyclist per minute, so the chance that a car driver will meet a cyclist on the bicycle street will be large. The larger the volume of cyclists, the more car drivers will adjust their speed to the cyclists on the bicycle street.

Considering the implementation of bicycle streets, additional points have been added. So is it advised to apply bicycle path lane lines on the bicycle street to improve the recognisability. The rabat strip should be integrated with the gutter to discourage cyclists to cycle on the rabat strip. When the rabat strip and gutter are integrated, cyclists will associate the rabat strip with the gutter and will probably not cycle there. Other changes are the recommendations to apply raised intersections on the bicycle street to lower the speed of mopeds and motorized vehicles and the use of one standard traffic sign, the traffic sign shown in Figure 33 on all bicycle streets.

Furthermore, the dimensions of the rabat and driving strip have been changed. The rabat strip is a bit smaller and the driving strip wider to increase the comfort of cyclists cycling on the bicycle street. By widening the driving strip, overtaking cyclists will not hinder the other cyclists on the bicycle street.


fietsstraat
auto te gast
74-ST-SL

TABLE 11: ADJUSTED GUIDELINES FOR BICYCLE STREETS, BASED ON THE GUIDELINES THAT ARE PRESENT IN THE DESIGN MANUAL FOR BICYCLE TRAFFIC (CROW, 2007) AND ASVV2012 (CROW, 2012).

Description	**Single-lane bicycle street**
Function	High quality bicycle connection, shared with motorized traffic
Application	• Access road • Within the built-up area • Speed limit: 30 km/h • Main bicycle route • $I_{bicycle} \geq I_{car}$ • $I_{bicycle} \geq$ 1000 cyclists/day
Implementation	• Asphalt driving strip • Red-coloured asphalt • Bicycle path lane lines in the middle of driving strip • Rabat strip paved with black/grey elements • Rabat strip integrated with gutter • Priority for bicycle street on intersections • Raised intersections with crossing streets • Continuing red asphalt strip and rabat strip on raised intersections • Route guidance if necessary • Stop prohibition on bicycle street • No parking on carriageway • Repetitive use of blue bicycle street traffic sign
Dimensioning	• Width carriageway (a): 4.50 metres • Width rabat strip (b): 0.5 metres (car-car) or 0.75 (car-truck) • Width driving strip (c): 3.5 metres 
Considerations	• Comfortable for cyclists • Clear for car drivers that they are using a main bicycle route • Could be attractive for cars without additional traffic regulation measures • High speeds of mopeds on bicycle street
Combination possibilities	• Parallel parking spots with safety zone between rabat strip and parking spot • Additional speed bumps when the distance between two intersections is large
Alternatives	• No alternatives, apply only this the design to improve recognisability

7 CONCLUSIONS

The conclusions about the traffic safety of bicycle streets are formulated per research question. The research questions are formulated in section 1.6.3. However, not only the answers to the research questions are given. Interesting conclusions that have been drawn during the research are also captured in this chapter.

The conclusions are ordered according to the research steps. First the conclusions considering the place of bicycle streets in the network have been formulated. The next section deals with the conclusions related to the functions of a bicycle street. Then the conclusions regarding the driving behaviour on the bicycle street are given, followed by the conclusions about the design. In the last section, the main research question is answered.

7.1 NETWORK

While the literature study shows that bicycle streets should lower the mesh size of bicycle amenities in large residential areas, not all studied bicycle streets meet this theory. Some of the bicycle streets provide an alternative, parallel route for the route along a distributor road. Other bicycle streets provide a shortcut for cyclists, compared with the route via the distributor roads. Nevertheless, some of the bicycle streets indeed are routed through a residential area and lower the mesh size of the bicycle amenities. Based on those observations could be concluded that the application possibilities of bicycle streets are broader than just lowering the mesh size of bicycle amenities in an urban network.

The attractiveness of the bicycle street for through-going motorized traffic depends on the position in the urban network. On an ideal bicycle street, only local traffic is present. The bicycle street should therefore not be attractive for through-going motorized traffic. The attractiveness on all the bicycle streets is decreased by one or more traffic measures, such as cuts for motorized traffic or mandatory driving directions for motor vehicles. Those measures are necessary to reduce the volume of motorized traffic on the bicycle street, since the route of the bicycle street is in most cases not only attractive for cyclists, but also for motorized traffic.

A bicycle street can fulfil different roles in a bicycle network. All the studied bicycle streets accommodate bicycle traffic on a main bicycle route. A main bicycle route often connects residential areas with the city centre and is therefore used by a large volume of cyclists. The main bicycle route mostly contains different kinds of bicycle amenities and the bicycle street is one of them. The bicycle street fills often a missing link between two other bicycle amenities, such as two bicycle paths.

Bicycle streets are always categorized as access roads. Access roads are considered as safer roads than distributor roads. However, along almost all distributor roads bicycle amenities are available, while on access roads mostly no bicycle amenities are available. On distributor roads with bicycle amenities, many crashes between motor vehicles and cyclists occur on intersections. (Schepers et al., 2011). Bicycle streets could be used to provide cyclists a safer alternative for the route along the distributor road.

Especially the design of a single-lane bicycle street contributes to the traffic safety for cyclists. In this design, the speeds of motorized vehicles are often rather low due to the small profile. Cyclists are also cycling more in the middle of the street, which gives cyclists a more prominent position on the road. The position more in the middle of the street also enlarges the obstacle free zone for cyclists, making the bicycle street forgiving.

7.2 FUNCTIONS

Based on the Sustainable Safety vision could be concluded that a bicycle street has at the first place a traffic function. Within a traffic function, three functions are distinguished: an access, a distributing or a flow function. Those functions differ on a bicycle street for the different user classes. In theory, a bicycle street is an access road and has therefore an access function for motor vehicles, mopeds and cyclists. A bicycle street differs from other access roads, since the street has also a flow function for cyclists. In practice, the access function for motor vehicles and mopeds is not naturally present on all the studied bicycle streets, since a part of the motor vehicles and mopeds is through-going traffic.

Bicycle streets are not monofunctional and could be categorized as ‘grey roads’ (Dijkstra et al., 2007). On the bicycle streets, conflicts have been observed between cars with an access function and cyclists with a flow function. Cars parking or stopping on or along the bicycle street are obstacles for cyclists flowing on the bicycle street. If the access function is relatively unimportant compared with the flow function, the probability of a conflict between a car stopping or parking on the bicycle street and a cyclist cycling on the bicycle street is rather small. If the access function becomes more important, due to for example shops or offices along the bicycle street, the probability of conflicts increases and the bicycle street becomes more unsafe.

The presence of through-going mopeds on the bicycle street is also a serious threat for the traffic safety. Those mopeds often drive at a much higher speed than cyclists on the bicycle street. The speed of mopeds is hardly influenced by design elements such as a small profile or speed bumps. The presence of mopeds on the bicycle street does therefore negatively contribute to the traffic safety on the bicycle street.

Another aspect that negatively contributes to the traffic safety of bicycle streets is the presence of heavy vehicles such as trucks or busses on the bicycle street because of the mass difference between those type of vehicles and cyclists.

If many heavy vehicles are using the bicycle street, the probability of two heavy vehicles meeting each other on the bicycle street is great. The width of the bicycle street should therefore be enlarged to accommodate two heavy vehicles passing each other. This extra width leads to an increase in the speed of cars on the bicycle street, since the speed depends for an important part on the width of the profile. The traffic safety is negatively influenced by the higher speeds of cars due to the wider profile and the presence of trucks.

7.3 Behaviour

It can be concluded that the behaviour of road users on the bicycle street differs from the behaviour intended by traffic engineers. Especially on two-lane bicycle streets, the intended behaviour is not recognizable in reality. The observed behaviour is that cars do not stay behind the cyclists on their lane, but overtake cyclists directly whenever possible. This type of bicycle streets has often a wider profile and the speeds are therefore rather high on those streets.

On single-lane bicycle streets the observed behaviour is more consistent with the intended behaviour. But also on this type of bicycle streets, cars overtake cyclists whenever possible. However, the profile which forces cyclists to cycle more in the middle of the street makes it harder for cars to pass cyclists. Some cyclists choose to cycle on the rabat strip instead of the asphalt driving strip. This behaviour gives car drivers the possibility to speed up on the driving strip.

Traffic engineers have further intended that traffic on the bicycle street has priority. Whether crossing traffic gives priority to traffic on the bicycle street depends on the layout of the intersection. If the priority is regulated by shark’s teeth, crossing traffic often does not stop completely at the intersection and tends to pick gaps between cyclists that are too small. When the priority is regulated by an exit construction, crossing traffic stops and picks a gap that is large enough. An exit construction is therefore a safer choice than the application of shark’s teeth. Exit constructions are mostly applied along single-lane bicycle streets, while at two-lane streets priority is often regulated by shark’s teeth.

Further the influence of cars parked along the bicycle street was studied. Too less conflicts between cars arriving or departing from a parking spot and other road users of the bicycle street have been observed to draw good conclusions.

Observations that were made, are cars partly parked on the rabat strip and cars with opened doors blocking the rabat strip. Since the rabat strip continues along the whole bicycle street, cyclists are able to cycle on the rabat strip continuously. Those cyclists could conflict with opened doors and wrong parked cars, the rabat strip should therefore not be seen as an extra safety space between parking spots and bicycle street.

Considering the speeds of the different categories of road users can be concluded that the speed differences between the categories are rather high. The traffic flow on the bicycle street is therefore not considered homogeneous. The speeds of a majority of the mopeds and cars on the bicycle street are not within safe limits. On all the studied bicycle streets, the 85 percentile speed value of cars exceeds the safe speed limit of 30 km/h.

On single-lane bicycle streets cars adjust their speed in the neighbourhood of cyclists. However, on two-lane bicycle streets, especially the ones with a wide profile, cars can pass cyclists without adjusting their speed. The speed behaviour of cars on single-lane bicycle streets is therefore safer than on two-lane bicycle streets.

In the common guidelines for bicycle streets is prescribed that the volume of cyclists should be higher than the volume of cars to reach the intended behaviour on the bicycle street. It can be concluded that the ratio cyclists/motor vehicles does not influence the speed choice of cars on the bicycle street.

Though, it can be concluded that the volume of cyclists influences the speed choice of cars on two-lane bicycle streets. The more cyclists, the lower the speed of the cars on this type of bicycle street. On single-lane bicycle streets, the speed choice does not depend on the volume of cyclists. An explanation for this difference can be found in the difference in profile widths of both types of bicycle streets.

7.4 Design

The differences in profiles do not contribute to the recognisability of bicycle streets. Bicycle streets in the Netherlands have different appearances and even within one type of bicycle streets, variations in the applied design elements can be found. The application of different types of bicycle streets and the existence of variations within the same type of design in combination with the limited amount of bicycle streets in the Netherlands creates a lack of recognisability. The behaviour of other traffic on the bicycle street is therefore not always predictable for users of the bicycle street. It can be concluded that the recognisability of the bicycle streets has to be improved.

Bicycle streets do not meet all the principles of Sustainable Safety, so it is useful to adjust the designs to improve the traffic safety. Bicycle streets are a valuable contribution to the designer's toolbox and should remain available for future applications. However, the following lessons can be learned from the studied bicycle streets. To improve the recognisability of bicycle streets, one standard design with design elements associated to bicycle paths should be applied. Besides the principles of predictability and recognisability, improvements can be made related to the principles of homogeneity and functionality.

Since bicycle streets are not monofunctional, conflicts occur among traffic participants with different traffic functions, especially motor vehicles with an access function and cyclists with a flow function. With some design adjustments, for example the application of an extra safety zone between the parking spot and the rabat strip, the number of potential conflicts between the different traffic functions can be reduced. However, the number of potential conflicts cannot be reduced to zero. To safely deal with those conflicts, the design should physical forgive mistakes of traffic participants.

For social forgivingness, a lower speed on conflict areas is needed. On the studied bicycle streets, the speeds are not within safe limits. Additional speed regulating measures such as speed bumps are therefore necessary. Those additional measures should especially reduce the speed on the most important conflict areas on the bicycle street: the intersections with crossing streets.

According to the proposed improvements of bicycle streets, new design recommendations have been formulated. The most important conclusion states that there should be one standard, recognisable design. It is recommended to choose the single-lane bicycle street as standard design and to improve the recognisability by adding bicycle path lining in the middle of the street. Furthermore should the recognisability be improved by the application of one standard traffic sign for all the bicycle streets in the Netherlands.

To clarify the function of the rabat strip, the rabat strip should be integrated with the gutter. It will then be clear for cyclists that the rabat strip belongs to the road side. The rabat strip will therefore only be used by cars, since the asphalt driving strip is too small for two cars to pass each other. The rabat strips further enlarges the obstacle free zone for cyclists and makes it possible for cyclists to avoid mistakes of other road users.

Considering the homogeneity of the traffic on the bicycle street, attention should be paid to the speed choice of motor vehicles on the bicycle street. The speed choice is influenced by the profile in the first place. The smaller the profile, the lower the speed. The minimum width of 4.5 metres is therefore the optimal width of the bicycle street. A width of 5.0 metres is possible, if there is a reasonable chance for two trucks meeting each other on the bicycle street. A wider profile leads to too high speeds on the bicycle street. If a wider profile is necessary, due to a high volume of trucks or busses on the street, a bicycle street design should not be applied on that street.

Since only the application of a narrow profile does not necessary lead to safe speeds on the bicycle street, other speed reducing measures are necessary. Especially on conflict areas the speeds need to be reduced. By applying raised intersections on the bicycle street, the speeds are reduced on the intersections with crossing streets. On those intersections, the red asphalt strip of the bicycle street should continue and priority should be regulated by shark's teeth on the crossing streets.

7.5 Main research question

Based on the research that has been carried out, it is possible to answer the main research question that has been formulated in section 1.6.3. The main research question is the following:

Is it possible to improve the design of bicycle streets in such way that the number of conflicts of cyclists with other cyclists or other users of the bicycle street could be reduced to improve the traffic safety on the bicycle street?

A large reduction in the number of conflicts cannot be achieved via an improved design, since the main cause of the conflicts can be found in the mix of functions on the bicycle street and not in the design. However, the traffic safety can be improved by reducing the effects of those conflicts. Attention should therefore be paid to the forgivingness of the bicycle street itself, its environment and its users. The forgivingness of the bicycle street and its environment can be improved via the design, while for the forgivingness of its users the homogeneity and predictability have to be improved. This can be achieved by applying one standard design for bicycle streets with extra attention for the speeds of mopeds and motor vehicles on the bicycle street.

8 RECOMMENDATIONS

In this chapter, recommendations are made based on the conclusions of the research. Recommendations for future research on bicycle streets are formulated in the first section. In the second section, recommendations for road authorities who are considering the choice for a bicycle street are made. The next section contains recommendations for traffic engineers designing bicycle streets. In the last section, practical recommendations are given for the road authorities of the eight case studies in this research, focussing on those bicycle streets in particular.

8.1 FUTURE RESEARCH

For future research, it is recommended to study a larger sample with more bicycle streets. The selection of eight bicycle streets is too small to draw significant conclusions from. With a larger benchmark, significant conclusions can be drawn about the driving behaviour on the bicycle street. A larger benchmark makes it further possible to determine which design elements influence the driving behaviour and which elements do not.

It is further recommended to study the recognisability of bicycle streets. The drawn conclusions about the recognisability of bicycle streets were based on several small questionnaires, mostly carried out directly after opening of the bicycle street. Also knowledge about Human Factors in traffic is used to test the recognisability. It is interesting to carry out a questionnaire among a large group of respondents, representative for the Dutch population, to study how well-known the concept of bicycle streets is and what design elements make a bicycle street recognisable as such.

The effects of the proposed adjustments of bicycle streets can also be studied. This could be done by studying the driving behaviour on the bicycle street before adjustments are made, and studying the driving behaviour after adjustments are made. Monitoring the driving behaviour before and after the adjustments makes it possible to compare both situations and to determine the effects of the adjustments.

The current guidelines for bicycle streets are mainly based on existing guidelines and expert judgements. The research provides a new view on those guidelines. It is therefore recommended to review those guidelines based on the insights provided by this and future studies on bicycle streets. Lessons learned from existing bicycle streets will be translated into improved guidelines.

In the current guidelines, a ratio for the volumes cyclists/motor vehicles with a value of two till four is mentioned. This means that on a successful bicycle street, the volume of cyclists is two till four times as large as the volume of motor vehicles. In this study has been concluded that the ratio does not influence the performance of the bicycle street. However, it could be useful to have an indication about a minimum number of cyclists and a maximum number of motor vehicles for the reviewed guidelines. Those numbers cannot be drawn from this study, new research is recommended to determine those numbers.

It is also recommended to study the effects of bicycle streets on a network level. In this research should be studied whether the route choice of cyclists changes after the opening of a bicycle street. When bicycle traffic chooses the bicycle street, bicycle streets could be used to unbundle bicycle and motorized traffic by providing an attractive route via access roads instead of distributor roads. If it is possible to create attractive routes via access roads instead of via distributor roads, then bicycle streets can seriously contribute to the overall traffic safety of cyclists.

8.2 ROAD AUTHORITIES

When road authorities consider to reconstruct a street into a bicycle street, it is recommended that they think about the current traffic composition on the street and the position of the street in the network. It is recommended to only apply a bicycle street when cyclists are already the dominant users of the street.

It is further important to think about the function of the street for motorized traffic. If the access function for motorized traffic is relatively important, it is recommended to not apply a bicycle street on that street. Also when the volume of heavy vehicles is high, a bicycle street is not the right choice.

8.3 TRAFFIC ENGINEERS

For traffic engineers designing bicycle streets, recommendations have been formulated based on the four Sustainable Safety principles for infrastructure.

It is recommended to test the functions of the bicycle street before the design process starts. A bicycle street should have a clear flow function for cyclists and the access function for motorized vehicles should be relatively unimportant. If the access function becomes too important, a bicycle street is not the best solution for that street.

It is further recommended to reduce the speeds of motor vehicles on bicycle street by the application of raised intersections. Those raised intersections reduce the speeds of traffic on the bicycle street and the crossing streets. If the intersections of the bicycle street are located close to each other, an exit construction can be applied for the crossing streets. If the distance between the intersections is great, additional speed bumps are recommended.

To improve the predictability and recognisability, only one design and one traffic sign should be used for bicycle streets. It is recommended to design the bicycle street in such way that road users associate the bicycle street with a bicycle path.

Extra attention should be paid to the physical forgivingness of the bicycle street and its environment. It is recommended to create an unattractive rabat strip that incidentally is used by cyclists on the bicycle street.

8.4 CASE STUDIES

Eight bicycle streets have been selected for this research as case study. Recommendations have been formulated for each bicycle street on a long, medium and short term level. Short term measures are often small adjustments to improve the bicycle street fast and at a low cost. On a longer term, it is recommended that those bicycle streets are reconstructed according to the proposed guidelines in chapter 6.

Alkmaar

Long term: reconsider the application of a two-lane bicycle street at the Frieseweg. A narrower profile and the application of a single-lane bicycle street is here recommended. If the medium term and short term recommendations cannot be followed up, the application of a bicycle street should be reconsidered.

Medium term: Reroute the busses driving on the Frieseweg, they are a serious threat for traffic safety.

Short term: Close the moving barrier at the end of the bicycle street during the whole day instead of only during the night. Through-going traffic will be banned from the Frieseweg and the volume of motor vehicles will therewith be reduced.

Castricum

Long term: On the long term, the application of a bicycle street should be reconsidered. Since the access functions are strongly represented at the bicycle street, a shared space would fit the situation better.

Medium term: Try to manage the supply of shops, bars and restaurants along the Dorpsstraat in such way that trucks do not block the bicycle street during the busiest hours of the day.

Short term: Create a cut for motorized traffic to ban motorized traffic from the bicycle street and reduce the volume of motor vehicles on the bicycle street.

Delft

Long term: The application of a two-lane bicycle street should be reconsidered. Apply a single-lane bicycle street with a narrower profile to reduce the speeds of motor vehicles on the Ezelsveldlaan.

Medium term: Influence the speed choice of motor vehicles on the bicycle street by the application of a speed bump.

Short term: The police should control the speeds of motor vehicles on the Ezelsveldlaan on a more regular basis.

Zoetermeer

Long term: To improve the recognisability of bicycle streets, the two-lane bicycle street should be reconstructed into a single-lane bicycle street with bicycle path lining in the middle of the street. The street has already a narrow profile, so an adjustment of the profile is not needed.

Medium term: Cars parked on the bicycle street should be prevented. Parking spots should be realised along the bicycle street or cars should be parked on private property.

Short term: The speeds of mopeds on the bicycle street are too high. It is therefore recommended that the police will control the speed of mopeds on the bicycle street on a regular basis.

Haarlem

Long term: The rabat strip of the bicycle street should be integrated with the gutter of the street.

Medium term: No recommendations.

Short term: No recommendations.

Houten

Long term: No recommendations.

Medium term: No recommendations.

Short term: The bicycle street can be improved by adding bicycle path lining in the middle of the bicycle street.

Oss

Long term: Integrate the gutter with the rabat strip to clarify the intended behaviour of the rabat strip.

Medium term: Apply speed bumps or raised intersections on the bicycle street to lower the speeds of motor vehicles.

Short term: Add bicycle path lining to the bicycle street to improve the recognisability of the bicycle street.

Zwolle

Long term: On a long term, the rabat strip should be integrated with the gutter to make the rabat strip less attractive for cyclists.

Medium term: The application of speed bumps or raised intersections on the bicycle street will help to reduce the speeds of motor vehicles on the bicycle street.

Short term: Bicycle path lining should be added to improve the recognisability of the bicycle street.

9 DISCUSSION

The conclusions of the research are categorized according the colours of a traffic light.

Conclusions that are based on only a couple of observations or opinions are categorized as red light results. The probability that those conclusions have been based on events that occurred by chance is great. Extensive research is needed to verify the conclusions in this section.

Conclusions based on a more firm argumentation are categorized as yellow light results. The argumentation gives a good indication that the conclusions may be true, but extra research is needed for the verification of those conclusions. The chance that those conclusions have been based on events that occurred by chance is less great than in the case of red light results, since those events have been observed more often.

Conclusions supported by good arguments and values are considered as green light results. Those conclusions are very well argued and the core of the research. Those conclusions should be validated by repeating the research with a larger sample of bicycle streets.

Before the different categories are described, some general comments on the methodology and research are given.

9.1 GENERAL COMMENTS

The research is for a large part based on the study of eight bicycle streets. Those streets have been chosen quite randomly and do not cover the whole variety of bicycle streets in the Netherlands. An important choice criterion was that the chosen bicycle streets should be single- or two-lane bicycle streets. Other types or mixes of types are not taken into account. Also one directional bicycle streets have not been taken into account, to make a fair comparison between the bicycle streets possible. Since those bicycle streets differ in traffic composition and design from the selected bicycle streets, the results of this research cannot be one-on-one copied.

The selection of four streets per type of bicycle street is based on several criteria. However, the criteria were not that specific and the selection of four streets is so small, that outliers could seriously affect the results. In this research, the bicycle street in Alkmaar can be considered as an outlier. The selection of streets is too small to consider Alkmaar as a significant outlier. The results have therefore been taken into account, since those results provide further information about aspects that do not contribute to successful bicycle streets.

This research has been based on literature studies and empirical research methods as observations and road counts. The study has therewith a strong traffic engineering character. One should also have studied the bicycle street and its environment from an urban planning point of view. This angle of incidence will provide other insights in the design of bicycle streets and will require another research methods.

In this research, no questionnaires were spread among the users of the bicycle street. Questionnaires among users could have provided interesting results about their perceptions. However, questionnaires have been spread among the road authorities of the eight selected bicycle streets. These questionnaires have been answered by a majority of the road authorities and provide besides technical information also some interesting information about the political choices that are made before a bicycle street is realised. It is certainly recommended to further investigate the political choices that are made before a bicycle street is realised.

9.2 RED LIGHT RESULTS

There has been concluded that on intersections where the priority is regulated with an exit construction, crossing traffic gives priority to traffic on the bicycle street. On intersections where the priority is regulated with shark's teeth, crossing traffic often overestimates the gap between two cyclists on the bicycle street. This conclusion has been based on the observation of eight intersections between a bicycle street and a crossing street. On some of the intersections, there was a large traffic flow crossing the bicycle street, while on other intersections only a few crossing vehicles have been observed. So this conclusion is only based on a couple of observations. However, it is clear that traffic crossing the bicycle street via an exit construction will drive at a lower speed than traffic that is not slowed down by an exit construction. Traffic at a slower speed will have more time to estimate the size of the gap and need a larger gap than traffic at a higher speed. Traffic crossing at a low speed will therefore not often choose a gap that is too small.

To support the conclusions above, more observations are needed. Therefore a longer observation period per bicycle street is needed, but also more bicycle streets should be investigated to draw significant conclusions.

9.3 Yellow light results

The functions of the bicycle streets have been determined based on a theoretical framework. This theoretical framework was developed based on a literature study. This literature study contains many Dutch articles, since those are the best applicable at bicycle streets in the Netherlands. The result is that this theoretical framework has been based on the articles of only a couple of researchers. However, on an international aspect not that many articles could be found that are applicable, especially since the literature is rather limited on this subject.

The analysis of the functions of the bicycle streets based on the theoretical framework has mainly been carried out via public available sources. During the observations has been looked for additional functions on the bicycle street and some function analyses have been adjusted. However, it is still possible that some characteristics and functions of the bicycle street have been missed. Nevertheless, it can be assumed that the most important functions are found and taken into account, since those functions are the most dominant on the bicycle street.

The traffic composition on the bicycle street has been studied with data collected by road tube counters. Those road tube counters register 95% of the vehicles correctly, but have problems to identify each bicycle in a large group of cyclists. Those large groups of cyclists are identified as vehicles with many axles and deleted from the dataset. The volume of cyclists on the bicycle street is therefore underestimated. The traffic counts have therefore been compared with older available traffic counts and there can be concluded that the order of magnitude of the volume of cyclists is correct.

The road tube counters were placed on the bicycle streets during one week, the week of the Easter holiday. Therefore, on the Friday before and the Monday after the Easter holiday less traffic was measured than on a normal workday. The Monday after the Easter holiday has therefore not been taken into account, the Friday before the Easter holiday was taken into account and the workday averages are therefore a bit lower than the workday averages measured during a normal week. However, not the exact numbers were interesting, but the order of magnitude of the volumes of different user categories. Since most days of the week were normal workdays, the order of magnitude is reliable.

In the research was looked for a relation between the profile and the speed choice of car drivers. Therefore, a correlation between the width of the street and the average speed was investigated. A scatter plot in which the width of the street was plotted against the average speed, showed an indication for a relation between the width of the street and the average speed. This relation is not significant, since only eight data points have been used. However, the found relation is consistent with the conclusions of Van Hal, Temme and Van der Heijden (2002), who state that the profile of the street influences the driven speed on a street.

Conclusions about cars parked or parking along the bicycle street and conclusions about cars or trucks stopping on the bicycle street have been based on only a couple of conflicts that have been observed. It is therefore not excluded that those conflicts were observed by chance or that other conflicts not have been observed. The most important conclusions that have been drawn about vehicles parking or stopping on the bicycle street are: there is an additional safety zone needed between the parking spot and the rabat strip since opened doors block the rabat strip and vehicles stopping on the bicycle street are serious obstacles for cyclists cycling on the bicycle street. Those conflicts were observed only a couple of times. However, the occurrence of those conflicts can also be explained from a traffic engineering point of view, taking the dimensions of the different design elements of the bicycle street into account. More extensive research will therefore probably support those conclusions.

The conclusion about the forgivingness of both types of bicycle streets is based on the observations at the eight selected bicycle streets. From those observations is concluded that cyclists often cycle close to the rabat strip and not to the median. In case of a mistake of another road user, cyclists can therefore quickly move to the rabat strip, while the median is often too far away. The single-lane bicycle street design is therefore considered as more forgiving than the two-lane bicycle street design. This conclusion is based on a feeling of common sense and not directly supported by observations or literature. However, from a traffic engineering point of view those conclusions can be supported. If the research is extended and more observations are done, it is likely that this conclusion will be verified.

Conclusions about the position on the road of different user categories have been based on observations at the bicycle street. As already earlier stated: the observation time was rather short. The positions of vehicles passing were noted and based on the notes, a qualitative description of the positions on the road was created. The result was one standard for the position on the road, while in practice a lot of variation in the positions has been noticed. Information about the variations in position has been lost during the process. The generalized positions on the road have been analysed with the help of knowledge in the field of Human Factors and traffic. This analysis showed that the observed positions on the road could be explained by the use of knowledge in the field of Human Factors.

The knowledge in the field of Human Factors has also been used to test the recognisability of bicycle streets. This knowledge was integrated in the research by interviewing a colleague at Grontmij with knowledge in the field of Human Factors. The results of this interview were used to determine whether bicycle streets are recognisable and what elements make bicycle streets recognisable. The used theory has been supported by an article of Harms and Dicke-Ogenia (2011), but the focus on bicycle streets is not supported by other sources.

Extra research in the traffic safety of bicycle streets is needed to validate the conclusions stated in this section.

9.4 Green light results

Enough data has been collected to state that the speeds of a large part of the motor vehicles on bicycle streets are too high and above the safe speed limit of 30 km/h. On all the studied bicycle streets, speeds of motor vehicles are too high. Also the speeds of mopeds are too high on most of the studied bicycle streets. There can be concluded that in the current designs, not enough speed reducing elements are available.

In the guidelines for bicycle streets is stated that the volume of cyclists should at least be twice as high as the volume of motor vehicles to achieve the intended behaviour. In this study was tried to find a relation between the ratio cyclists/motor vehicles and the average speed of motor vehicles on the bicycle street. At none of the studied bicycle streets, this relation has been found. This conclusion is based on studying the average speed and ratio per hour for five days per week for all the eight selected bicycle streets. Since at none of the bicycle streets a relation has been found and no literature supporting this conclusion can be found, this conclusion is considered as a firm conclusion.

The conclusions above need to be studied in a comparable research with a larger sample. The results of this extensive research are needed to validate the conclusions in this section.

9.5 Conclusions

This research can be considered as a first step in determining the opportunities and threats of bicycle streets in the Netherlands. Strengths and weaknesses of two common types of bicycle streets have been charted and translated in design recommendations for future bicycle streets. The results indicate several interesting directions for new research. However, one should not use the results of this research as leading results for new guidelines for bicycle streets. Therefore, the studied sample of bicycle streets is too small.

The results of this research are therefore useful for the CROW as a starting point for the revision of the design guidelines for bicycle streets. The lessons learned from the bicycle streets in practice provide a good starting point for the revision of the guidelines, however extra research will be needed before.

The Fietsberaad may be further interested in the results of this study, since the results provide a clear insight in the traffic safety of bicycle streets. The research provides handles for road authorities and traffic engineers designing bicycle streets. It can be motivation to encourage further investigation in the field of bicycle streets and traffic safety.

For the SWOV, those results are useful for further investigation of unbundling cyclists from motor vehicles by providing safe and attractive alternatives via access roads.

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Appendix A: Function analysis

In the function analysis, the flow, urban and access functions have been analysed. For each bicycle street several maps are provided showing the main bicycle route and the position of the bicycle street in the network. With an orange colour, residential areas are indicated. A blue colour indicates an area with shops and other commercial activities, while a purple colour indicates an area with offices, industries or educational institutes. Only areas with a relation to the main bicycle route or bicycle street are coloured. Besides the areas, also a road hierarchy is given, showing the important distributor and through-going roads with a flow function.

Alkmaar, Frieseweg

The Frieseweg in Alkmaar has been reconstructed into a bicycle street in the summer of 2012. The main reason to reconstruct the Frieseweg were complaints of residents along the Frieseweg about the high intensities and speeds of motorized vehicles, the large number of heavy vehicles using the Frieseweg and the vibrations caused by those heavy vehicles. Furthermore, the Frieseweg is part of a main bicycle route connecting the residential areas north of the city centre with the city centre of Alkmaar. The reconstruction into a bicycle street aims on facilitating the large volumes of cyclist and reducing the number and speeds of motorized vehicles and especially heavy vehicles.

Flow functions

The Frieseweg is part of a main bicycle route north of the centre of Alkmaar. The main bicycle route connects the residential areas north of the city centre to the city centre of Alkmaar, see Figure 35. In the northern part of Alkmaar, 50,000 of the 90,000 residents of Alkmaar are living, so the main bicycle route is used by a lot of the residents of Alkmaar.

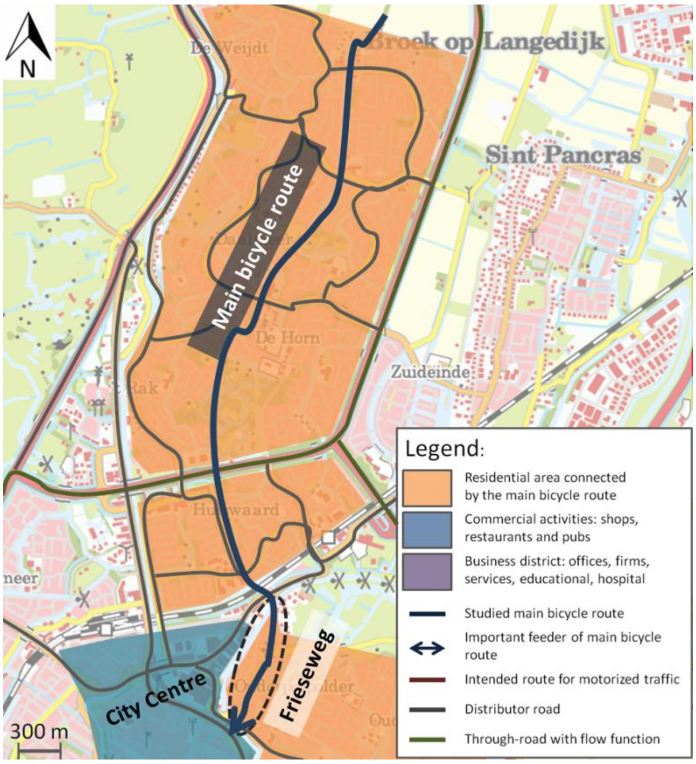

FIGURE 35: MAIN BICYCLE ROUTE FROM ALKMAAR-NOORD TO THE CITY CENTRE AND THE POSITION OF THE STUDIED BICYCLE STREET IN IT

FIGURE 36: TWO-LANE BICYCLE STREET AT THE FRIESEWEG WITH A WIDE PROFILE

At the south side of the Frieseweg the main bicycle route crosses the Noord-Holland canal. The main destination of the bicycle route is the city centre of Alkmaar at the south side of the canal.

The Frieseweg ends at the south side at an intersection with a distributor road, the Friesebrug. Here, bicycle tracks along the distributor road connect the Frieseweg with the city centre of Alkmaar. At the north side, the Frieseweg ends also at an intersection with a distributor road. The main bicycle route crosses the distributor road and continues as a cycle path to the north of Alkmaar.

The main bicycle route contains the following bicycle amenities: north of the Frieseweg the main bicycle route consists only of solo bicycle paths through the residential area. The Frieseweg itself is a two-lane bicycle street over the whole length. South of the Frieseweg, the main bicycle route crosses the canal following the bicycle tracks along the distributor road.

Urban functions

Along the Frieseweg, mainly houses are located. The type of houses vary along the road, along the southern part of the Frieseweg houses from the beginning of the 20^{th} century are located, at the northern part modern houses are located. Many houses along the Frieseweg do not have parking facilities on their own terrain, so public parking space has to be available. Along the Frieseweg some parking spaces have been realized, but the Frieseweg does also have a parallel road, facilitating the parking demand.

Along the Frieseweg also some small businesses are located. Those will probably generate some supply related truck traffic. It is not expected that those businesses have a serious effect on the parking demand.

The Frieseweg has a very wide profile, see Figure 36, with large green areas and a parallel road. The building densities along the street are quite low and there is quite a large distance between the house fronts and the edge of the street. A low speed is not naturally enforced by the profile of the street.

Access functions

The Frieseweg provides for motorized traffic a through-going connection from the city centre to the north of Alkmaar. As is shown in Figure 37, the Frieseweg provides a shorter route than the desired route via the distributor roads. The Frieseweg provides therefore an attractive route for cars between the city centre and the north of Alkmaar. Its attractiveness is reduced by a moving barrier installed at the north end of the Frieseweg. This moving barrier closes the northern part of the Frieseweg for motorized traffic from 21h till 9 h. During day times the moving barrier is not closed because of political reasons. The bicycle street design has been applied to discourage car drivers to take the Frieseweg.

FIGURE 37: POSITION OF BICYCLE STREET AND THE DESIRED ROUTE FOR MOTORIZED TRAFFIC

Furthermore, other ways of traffic regulation has not been applied on the Frieseweg to reduce the car intensities. Traffic is generated by the houses along the Frieseweg and the houses along the streets that are only accessible via the Frieseweg. Furthermore, the small businesses will generate a bit of motorized traffic. The play garden will mostly generate non-motorized traffic.

Besides the traffic that is generated at the bicycle street, also two bus lines are using the Frieseweg. Each bus line has a frequency of two busses per hour, so each hour four busses per direction are driving at the Frieseweg. In total eight busses per hour are using the bicycle street.

Conclusions

Given the functions of the Frieseweg, the Frieseweg could be seen as an atypical bicycle street, having many functions that should not be present at a bicycle street according to the conventional guidelines. At a bicycle street should only local traffic be present, having low intensities and low speeds and the number of trucks should certainly be limited. The Frieseweg had before the reconstruction through-going traffic, high intensities, high speeds and an extremely large volume of trucks. After the reconstruction there is still through-going traffic present at the bicycle street, but the intensities, speeds and number of trucks have been decreased. The profile does not enforce a low speed by itself, a lower speed should therefore be enforced by traffic measurements.

Busses should not be using a bicycle street. Eight busses per hour are using the Frieseweg in their route. For political reasons and the accessibility by public transport of the neighbourhood, it is not possible to divert the busses.

The combination of the through-going motorized traffic and busses with the main bicycle route on a street with a mixed profile could give conflicts since those functions are conflicting. In this case especially the combination of the busses with the main bicycle route is conflicting since the busses drive fast on the bicycle street and have a much larger mass than cyclists.

Castricum, Dorpsstraat

The Dorpsstraat in Castricum has been reconstructed into a bicycle street in 2010. Its realization was not undisputed since almost 8000 motorized vehicles per day were using the Dorpsstraat, together with almost 4000 cyclists per day. The choice for a bicycle street at this location is therefore remarkable. However, the municipality of Castricum and local cyclists federation are very enthusiastic about the bicycle street after its realization.

Flow functions

The Dorpsstraat is part of a main bicycle route connecting the newer residential areas in the north of Castricum with the facilities in the centre and the station of Castricum. Figure 38 shows the main bicycle route in Alkmaar and the desired route for motorized traffic. The main bicycle route could be extended in the north with the Alkmaarderstraatweg and the Willem de Rijkelaan, but the most important part of the main bicycle route and the part where a lot of cycle traffic is bundled is the Dorpsstraat. Especially the bundling of bicycle traffic on the Dorpsstraat due to the commercial activities along the Dorpsstraat makes this an important street for cyclists.

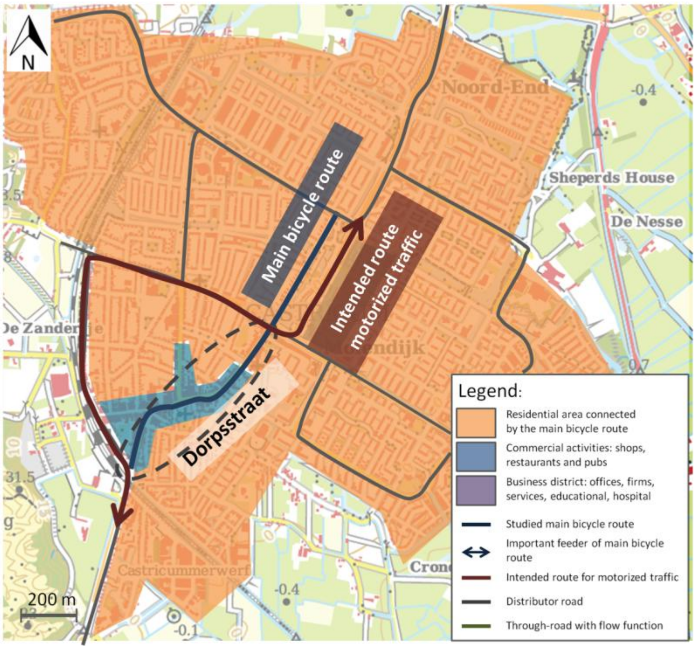

FIGURE 38: MAIN BICYCLE ROUTE IN CASTRICUM

FIGURE 39: TWO-LANE BICYCLE STREET AT THE DORPSSTRAAT IN CASTRICUM

The Dorpsstraat has a two-lane bicycle street design over the whole length. Other parts of the main bicycle route are normal access roads without bicycle amenities. The bicycle street ends at the north at a distributor road with a roundabout. The main bicycle route continues north of the roundabout and ends in the residential area in the north of Castricum. At the south, the Dorpsstraat ends at an intersection with a distributor road. Bicycle paths along the distributor road facilitate a safe position for cyclists at this location.

Urban functions

The Dorpsstraat was the central street of the village of Castricum. After the Second World War the village has grown fast and the Dorpsstraat is not any longer the central street of the village. However, it has still its central street functions. Along the street commercial activities such as shops, restaurants and pubs are located. The street is therefore also part of the night out area of Castricum. Figure 40 shows the street and its functions along the street.

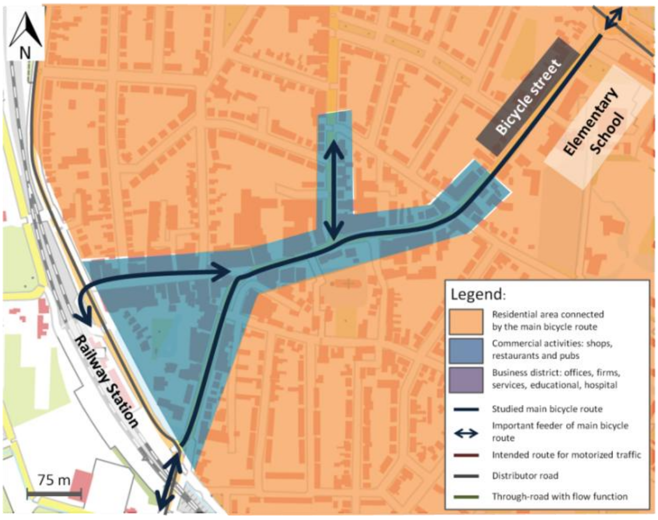

FIGURE 40: URBAN FUNCTIONS ALONG THE DORPSSTRAAT

Along the Dorpsstraat also other functions that are normally located along a central street could be found, such as two churches and an elementary school.

Besides the commercial activities along the Dorpsstraat, also residential functions such as houses and apartments are located along the Dorpsstraat. So a mix of functions could be found along the Dorpsstraat.

This mix of functions causes a high parking demand on the Dorpsstraat. The parking demand is facilitated by parking spots along the Dorpsstraat. For the Dorpsstraat a maximum parking time of two hours has been installed.

The street has a normal profile, varying a bit along the Dorpsstraat. Parked cars in parking spots on both sides of the street will visually narrow the street. Also trees along the street will narrow the profile. The profile of the Dorpsstraat will naturally enforce a lower speed. Along the Dorpsstraat, the building densities are medium high. Most houses along the Dorpsstraat do not have a front garden, so the distance between the house fronts and the parking spaces is not that large.

Access functions

The Dorpsstraat is open for through-going traffic. The desired route leads along the railway track, but the Dorpsstraat is an attractive route since it provides a much shorter route (see Figure 38). However, so far no traffic regulation measures have been implemented on the Dorpsstraat to make through-going traffic impossible or to reduce the volume of motorized vehicles on the Dorpsstraat. The reconstruction into a bicycle street has caused a reduction in the volume of motorized traffic on the Dorpsstraat, without further traffic regulating measurements.

The mix of functions along the Dorpsstraat will generate and attract a lot of motorized traffic. This will vary from residents who want to park their car in front of their home to heavy goods vehicles supplying the shops along the street and from consumers visiting the shops along the street to taxis during a night out. So it will be busy at the Dorpsstraat since a lot of traffic is generated by the activities along the street.

Most of the traffic that will be generated by the activities along the Dorpsstraat will be local traffic. This means that besides a quite large volume of motorized traffic also a large volume of cyclists and pedestrians will use the Dorpsstraat. This will be strengthened by the location of the railway station near to the Dorpsstraat, attracting a large volume of cyclists.

The Dorpsstraat is not used by busses or other forms of public transport.

Conclusions

The Dorpsstraat contains a mix of residential, commercial and public functions. It is not part of a main bicycle route in the way that has only a flow function, a lot of destinations of the main bicycle route are directly located along the bicycle street and the street has therefore also an important access function. The Dorpsstraat provides also a shortcut for the desired route for motorized traffic. Through-going traffic has not been prohibited so also a certain amount of through-going motorized traffic will use the bicycle street. Based on the functions of the Dorpsstraat, a large volume of motorized vehicles together with a large volume of cyclists will be expected. A part of the traffic, both motorized and cyclists, will have its destination at the bicycle street, another part will be through-going traffic. This mix could lead to conflicts, but also the large volume of cyclists will cause conflicts on the Dorpsstraat.

Delft, Ezelsveldlaan

The Ezelsveldlaan is situated at the edge of the city centre of Delft, between the Oostpoortbridge and the Zuidpoort. The Ezelsveldlaan has been reconstructed into a bicycle street in 2007, after opening of the new Zuidpoort shopping area.

Flow functions

The Ezelsveldlaan is part of the so-called 'Zoefroute'. The Zoefroute is a main bicycle route connecting Zoetermeer with De Lier via Pijnacker, Delfgauw, Delft and Den Hoorn. The route runs tangential with respect to the city centre, but also with respect to the station, university and other facilities in Delft. The route is an important east-west connection within the bicycle network of Delft and connects large residential areas with the hospital, the railway station, the city centre and the university. The route of this main bicycle route within Delft is given in Figure 41.

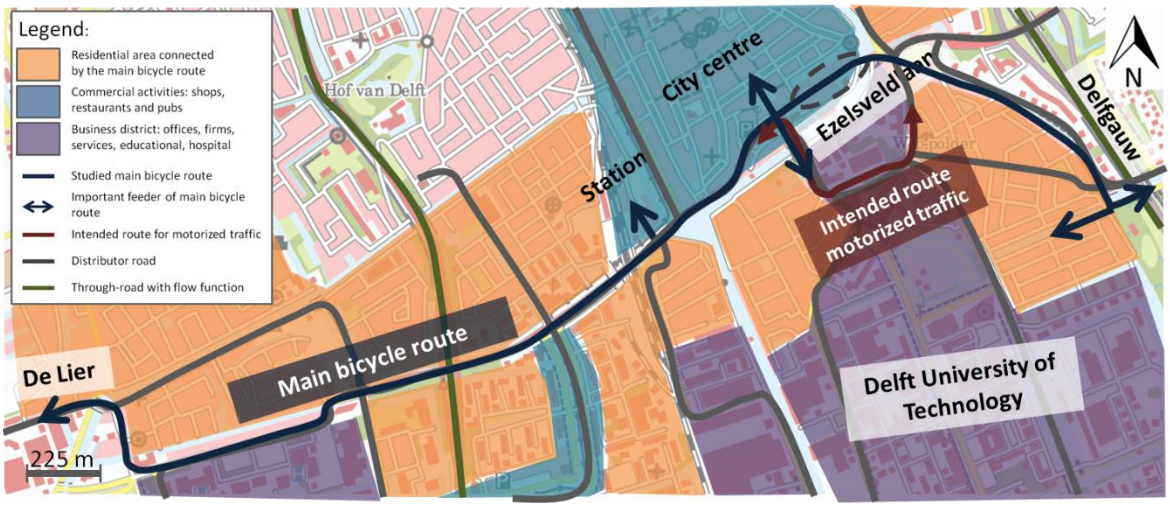

FIGURE 41: THE ROUTE OF THE 'ZOEFROUTE' IN DELFT

The route follows for a large part cycle paths along distributor roads. Along the Westlandseweg has a parallel road been reconstructed into a two-lane bicycle street and near the Oostpoortbridge a solo cycle path is available. The Ezelsveldlaan is a two-lane bicycle street, connecting the solo cycle path at the Oostpoortbridge with the cycle path along the Westvest.

The route ends in the residential areas of De Lier and Zoetermeer.

Urban functions

Along the Ezelsveldlaan, old university buildings from the beginning of the 20th century are situated, mixed with new apartment buildings, see Figure 42. In the buildings mainly housing is facilitated, but at street level some small businesses, dancing school and health care institutions are located.

FIGURE 42: TWO-LANE BICYCLE STREET AT THE EZELSVELDLAAN IN DELFT, HAVING OLD BUILDINGS ON ONE SITE AND NEW BUILDINGS ON THE OTHER SIDE. THE PARKING DEMAND IS FACILITATED BY PARKING SPOTS ALONG THE BICYCLE STREET.

Due to its location near the city centre and the presence of businesses and health care is the parking demand in the Ezelsveldlaan high. Therefore a parking ban has been applied to prevent parking on the bicycle street and the surrounding streets. To satisfy the parking demand, internal parking places have been realised in the new buildings along the Ezelsveldlaan. Along the Ezelsveldlaan also a few parking places have been realised.

The building densities along the street are high. The street has a wide profile with enough space for trees and pedestrians. The bicycle street itself is narrow and the median makes street look even more narrow. The profile of the street enforces a low driving speed for motorized vehicles.

In Figure 43 is the bicycle street with the functions in the neighbourhood related to the bicycle street given.

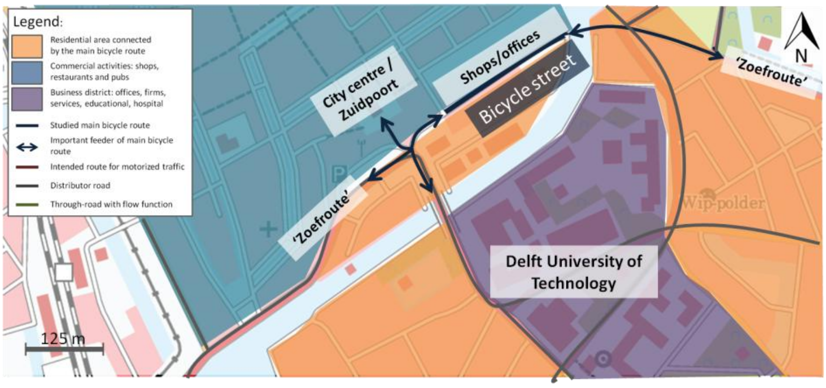

FIGURE 43: EZELSVELDLAAN WITH THE FUNCTIONS IN THE NEIGHBOURHOOD

Access functions

The Ezelsveldlaan is not suitable for through-going motorized traffic, since it is a cul-de-sac for motorized traffic. The Oostpoortbridge at the end of the street is only accessible for non-motorized traffic. This is regulated by poles blocking the street for motorized traffic.

The offices and houses will generate some motorized traffic, but since only local traffic will use the bicycle street will the intensities of motorized traffic be low. The street is also not part of a route for public transport.

Conclusions

The Ezelsveldlaan has no conflicting functions. Its main function is the flow function for cyclists, and due to the fact that the street is a cul-de-sac there is only a bit of motorized traffic expected on the bicycle street.

Zoetermeer, Zegwaartseweg

The Zegwaartseweg in Zoetermeer is the longest bicycle street in this study and one of the longest in the Netherlands. The street has been reconstructed into a bicycle street in 2012. The bicycle street interconnects many residential areas and business districts in Zoetermeer. The main bicycle route is illustrated in Figure 44.

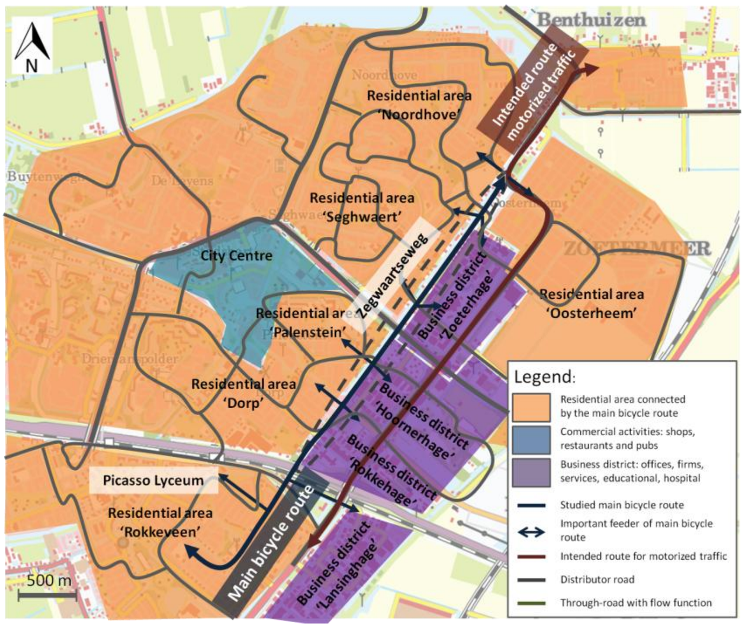

FIGURE 44: MAIN BICYCLE ROUTE IN ZOETERMEER

FIGURE 45: URBAN PROFILE OF THE TWO-LANE BICYCLE STREET IN ZOETERMEER. THE BICYCLE STREET LIES WITHIN THE BUILT-UP AREA.

Flow functions

The main bicycle route where the Zegwaartseweg is a part of, is the only non-radial bicycle route connecting the suburbs with the city centre. The Zegwaartseweg has radial position in the network relative to the city centre of Zoetermeer, but also the residential areas and business districts. It runs on the border between residential areas at the west and business districts at the east. The bicycle street is mapped in Figure 46.

The main bicycle route interconnects the different residential areas with each other as well as with the business districts. The route runs from Benthuizen in the north of Zoetermeer to the residential area 'Rokkeveen' in the south. Residential areas and business districts in between are linked to the bicycle street by several connections. Other important origins and destinations are not located directly along the street.

At the Zegwaartseweg, the two-lane bicycle street design has been applied over the whole length of the street. The bicycle street at the Zegwaartseweg has priority at almost all the intersections with other streets, while the rest of the main bicycle route does not have priority at intersections. One of the intersections between the bicycle street and a distributor road is shown in Figure 47.

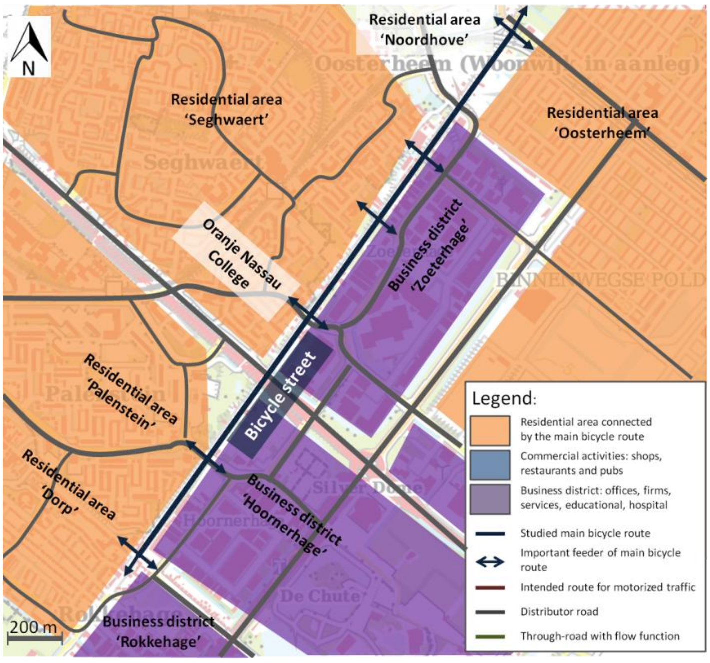

FIGURE 46: BICYCLE STREET WITH ITS ORIGINS AND DESTINATIONS

FIGURE 47: PRIORITY INTERSECTION AT THE BICYCLE STREET IN ZOETERMEER

At the north, the bicycle street ends at a main distributor road with bicycle paths in eastern and western directions, to the north the road continues via a distributor road with bicycle lanes. In the south, the main bicycle route ends in the middle of a traffic-calmed residential area.

Urban functions

A large variety of buildings could be found along the Zegwaartseweg. Houses, restaurants and agricultural firms are located here. The building density is very low and the profile does not always belong to an urban area, as can be seen in Figure 45. The profile is very wide due to a canal at the west side directly along the street. Houses are located at quite a distance from the bicycle street.

FIGURE 48: CARS PARKED ON THE BICYCLE STREET ARE AN OBSTACLE FOR CYCLISTS

Along the street, also several large green areas are situated. The wide profile, low building density and large green areas along the street do not support the 30 km/h speed limit at the Zegwaartseweg. Based on the profile only a 60 km/h speed limit should be expected.

Some of the functions will attract some traffic and could therefore cause a higher parking demand. There is no space available to park at the Zegwaartseweg, so the parking demand should be facilitated at private terrains.

There are no parking spots along the Zegwaartseweg. In Figure 48 can be seen that cars are parked on the bicycle street.

Access functions

The street could be an attractive route for motorized through-going traffic since it provides a straight and direct connection between several origins and destinations. Before the growth of Zoetermeer it was even the main connection between the old village of Zoetermeer and Benthuizen. The route is also very attractive due to the small amount of intersections and the nice environment.

Through-going motorized traffic has been made impossible by implementing several cuts for motorized traffic. Through-going motorized traffic is therefore only possible at a couple of short pieces road and the route has therefore become unattractive for motorized traffic.

The houses and firms along the Zegwaartseweg will generate some traffic. Especially the firms, since they will also generate some freight related traffic. However, due to the low building densities, the volume of motorized traffic at the bicycle street is expected to be not that high. Public transport is not using the bicycle street.

Conclusions

The Zegwaartseweg is not a normal access road within an urban area. The profile and environment do not always support the 30 km/h speed limit at the Zegwaartseweg. Due to the cuts for motorized traffic and the low building density, large volumes of motorized traffic are not expected at the Zegwaartseweg.

The street has a clear flow function for cyclists, since exchange of traffic will mainly take place at the intersections with other routes.

Haarlem, Venkelstraat

The Venkelstraat in Haarlem has been reconstructed into a bicycle street in 2005. The Venkelstraat is located in the southeastern part of Haarlem, in the residential area called Schalkwijk. The bicycle street has been realized to facilitate the large volume of cyclists on the Venkelstraat, since the Venkelstraat is part of the main bicycle route network of Haarlem.

Flow functions

The Venkelstraat is part of the main bicycle route that connects Schalkwijk with the city centre of Haarlem. It is also part of a smaller local bicycle network within Schalkwijk, facilitating a fast and safe connection for non-motorized traffic to the facilities in the centre of Schalkwijk. Furthermore, the Venkelstraat is a part of a school route to a secondary school along the Engelandlaan.

The main bicycle route follows north of the Venkelstraat the Kruidplein and connects there to the cycle path along the Europaweg and the Schipholweg. At the crossing with the river Spaarne, the route follows the cycle path along the Spaarne towards the city centre. South of the Venkelstraat, the route continues following the Engelandlaan. The main bicycle route is illustrated in Figure 49.

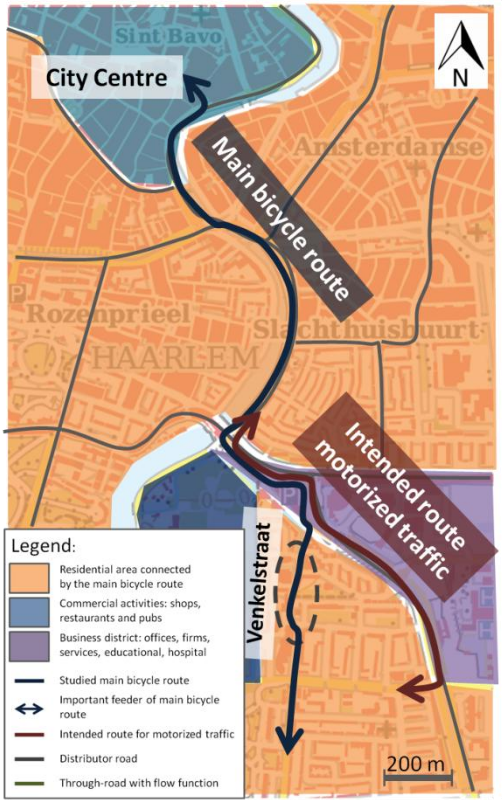

FIGURE 49: MAIN BICYCLE ROUTE IN HAARLEM


FIGURE 50: URBAN PROFILE OF THE BICYCLE STREET AT THE VENKELSTRAAT

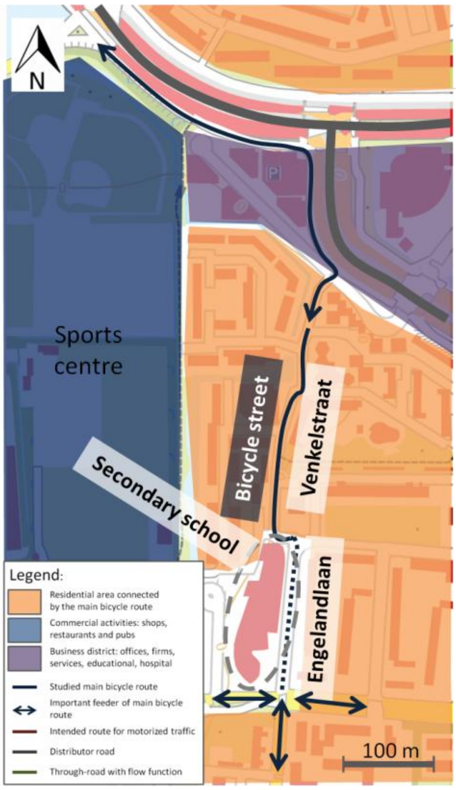

FIGURE 51: THE BICYCLE STREET IN THE VENKELSTRAAT AND ITS EXTENSION IN THE ENGELANDLAAN (DOTTED)

Origins and destinations of the route are the city centre of Haarlem with its facilities, the centre of Schalkwijk, the secondary school along the Engelandlaan and the houses in the northern part of Schalkwijk. North of the bicycle street the city centre of Haarlem is important, but also a lot of school kids will travel from the north over the bicycle street to the secondary school. South of the bicycle street the secondary school and the businesses along the Belgiëlaan are important origins and destinations, as well as the sport complexes at the west.

North of the Venkelstraat, the main bicycle route follows bicycle paths towards the city centre of Haarlem. South of the Venkelstraat, the Engelandlaan has also been reconstructed into a bicycle street after the realization of the Venkelstraat. Both the Venkelstraat and the Engelandlaan have a bicycle street single-lane bicycle street design of the street, see Figure 51.

The main bicycle route continues to the north following the Spaarne. The route is over the full length till the north of Haarlem equipped with cycle paths along a distributor road. The bicycle street at the Engelandlaan ends at the intersection with the Belgiëlaan. The main bicycle route splits here in local branches towards the sports complexes in the west, the businesses in the east and the residential areas in the south. All those branches are access roads, but are also equipped with bicycle lanes.

Urban functions

Along the Venkelstraat only houses are located. Those houses do not have parking space on their own terrain. Therefore parking spaces are realized along the bicycle street as can be seen in Figure 50, some of them in the same direction as the driving direction, others are situated perpendicular to the street.

In the south of the Venkelstraat, a secondary school is located (see Figure 51). This secondary school does not affect the bicycle street in the Venkelstraat directly since the entrance is not directly located at the Venkelstraat. There are no parking problems in the Venkelstraat that could be related to the school.

The Venkelstraat has a wide profile, with parked cars and some trees narrowing the profile. The building densities are medium high since there is a mix of higher apartment buildings and low semi-detached houses. The houses have a small front garden, so the distance between the house fronts and the street is small. A low speed is not directly enforced by a narrow profile, but by the curves in the profile.

Access functions

The Venkelstraat is categorized as an access road. The street provides access to the buildings along the street and some cul-de-sacs that are connected to the street. Through-going motorized traffic is possible, but the street is not attractive as it is not the shortest or fastest route for traffic without its origin or destination near to the Venkelstraat.

The route is attractive for cyclists due to its shortcut via the Kruidplein to the Europaweg. This shortcut is not open for cars, cars have to follow the Venkelstraat to the Europaweg, resulting in a detour. Therefore this route is not attractive for cars and other motorized traffic. Other traffic regulation measures are therefore not necessary and not applied in this case.

The houses along the Venkelstraat and the surrounding streets will not generate much motorized traffic. Only the school will generate some traffic, however most traffic will be students by bike or by foot. Except of some occasional trucks for garbage collection or a removal-van, no truck traffic is expected at the bicycle street.

Conclusions

The Venkelstraat has no conflicting functions. It has a pure access function for motorized traffic and is unattractive for through-going motorized traffic. So the cyclists on the main bicycle route will be mixed with motorized traffic having their origin or destination in the direct neighbourhood of the bicycle street. Not the profile of the street, but the curves in the street will enforce a low driving speed.

Houten, Prinses Ireneweg

The Prinses Ireneweg is located near the new centre and station of Houten. The Prinses Ireneweg has been reconstructed into a bicycle street in 2010. The street was a normal residential street and has been reconstructed into a single-lane bicycle street. The street is located in the older part of Houten, between the original village and the new city centre. The street has been reconstructed into a bicycle street in order to close a missing link in the bicycle network of Houten.

Flow functions

The Prinses Ireneweg is part of a main bicycle route connecting the south of Houten and the old village of Houten with the new city centre and station of Houten. The old village and the new city centre of Houten accommodate both many commercial activities such as shops, restaurants and pubs. Other destinations of the bicycle street are schools, public amenities and office areas in the city centre of Houten. The main bicycle route between the city centre of Houten and the south of Houten, the new residential area Castellum, is given in Figure 52.

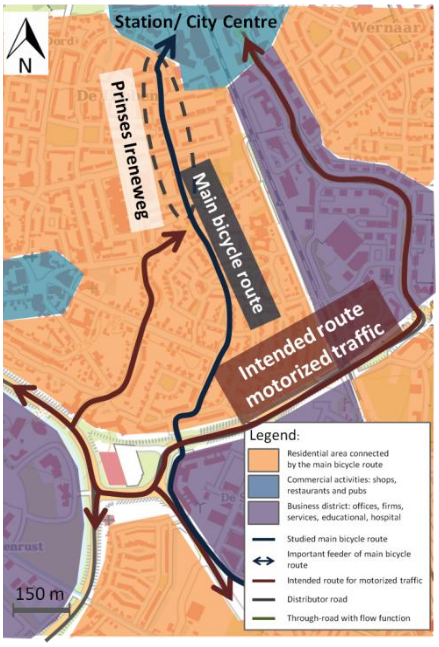

FIGURE 52: THE MAIN BICYCLE ROUTE BETWEEN THE CENTRE OF HOUTEN AND THE SOUTH OF HOUTEN

FIGURE 53: THE SINGLE-LANE BICYCLE STREET AT THE PRINSES IRENEWEG IN HOUTEN

Street designs that are applied on the main bicycle route are single-lane bicycle streets, solo cycle paths and traffic-calmed residential streets without special bicycle amenities. Bicycle streets in Houten are always connected to solo cycle paths at both ends.

Urban functions

Along the Prinses Ireneweg, mainly one-family houses are located as can be seen in Figure 53. Some houses have parking space on their own terrain, other houses not. Therefore parking amenities along the street have been realized. Both parking spots along the street as perpendicular to the street are implemented.

At the northern end of the bicycle street, the entrance to a secondary school for both cars and bikes is located. The parking place of the school is not large enough to facilitate the parking demand of the school. The parking pressure in the surrounding streets is therefore high.

Halfway the bicycle street a small day-care centre is located. This day-care centre does not cause parking problems on the bicycle street, since a lot of children are brought by bike and the day-care centre only has a couple of employees.

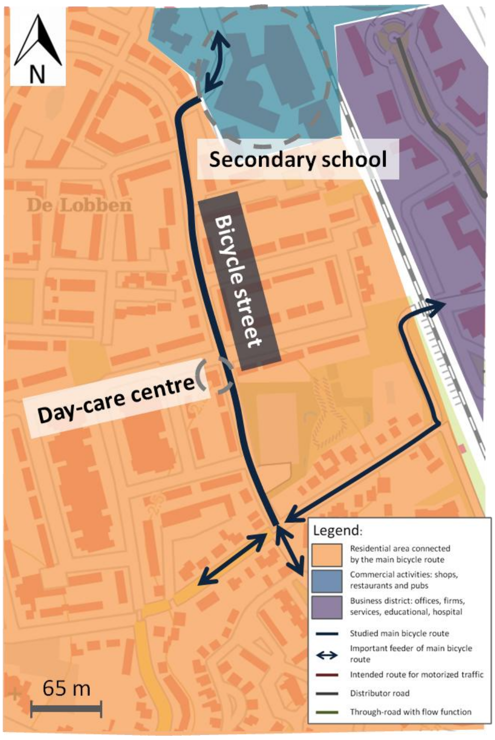

FIGURE 54: THE BICYCLE STREET AT THE PRINSES IRENEWEG

The building densities along the Prinses Ireneweg are low. Houses have a large front garden and the distance between the house fronts and the edge of the street is quite large. The profile of the street is narrowed by large trees along the street. However, the street itself is quite wide and straight, so could provoke higher speeds.

The bicycle street with the position of the day-care centre and the secondary school are given in Figure 54.

Access functions

The urban structure of Houten makes through-going motorized traffic through the residential areas impossible. The residential areas are retrieved by a distributor road leading traffic around Houten, outside the urban area. Motorized traffic on the bicycle street will have its origin or destination directly along the bicycle street or the surrounding streets.

The Prinses Ireneweg provides for a part of the large residential area of Houten a fast and direct connection to the distributor road. It is also an attractive route for motorized traffic since it is the only route with priority in the direct neighbourhood. Residents along the Prinses Ireneweg have complained about higher car intensities after the reconstruction into a bicycle street. However, measurements supporting this statement are not available since there have no measurements been executed before the reconstruction.

Since through-going motorized traffic is made impossible and motorized traffic is discouraged by the urban structure of Houten, no further traffic regulations have been implemented to reduce the volume of through-going motorized traffic on the bicycle street.

Traffic is generated by the houses along the street and the direct surrounding streets. Also the secondary school will generate a large volume of traffic, motorized and non-motorized. It will be busy on the road during morning peak-hour as the residents depart to commute to their work and students and employees of the school will arrive. At other times of the day it will probably be very quiet on the bicycle street, since the street will not generate a lot of motorized traffic outside the peak hours. Cyclists will also use the bicycle street outside the peak hour, but mostly not in large volumes. The secondary school could also generate some freight transport for provisioning of for example the canteen and the copy room.

Public transport is not using the Prinses Ireneweg.

Conclusions

The Prinses Ireneweg is a normal access road within a traffic-calmed residential area. Motorized traffic on the Prinses Ireneweg has its origin or destination directly along the street or the surrounding streets. The intensities of motorized traffic will be low. The elementary school at the end of the street will generate a lot of traffic. Most of the traffic will be cyclists, but also a significant volume of cars. Due to the elementary school, the parking pressure at the northern end of the bicycle street is quite high. This could lead to problems when cars are parked on the bicycle street. So based on this function analysis could be concluded that there are no problems expected based on conflicting functions at the bicycle street. Only the parking demand at the northern part could be too high and therefore cause problems. The profile of the street is attractive for residents and cyclists, but the wide profile of the straight road could provoke speeds higher than 30 km/h.

Oss, Asterstraat

The Asterstraat in Oss is part of one of the longest bicycle streets in the Netherlands. It has been reconstructed into a bicycle street in 2003 to provide an attractive route for cyclists from Heesch, a village south of Oss, to the centre of Oss. The street has been a lead for other municipalities that have decided to reconstruct streets into a bicycle street, since both bicycle street designs are applied in Oss.

Flow functions

The Asterstraat is part of the main bicycle route in Oss running from the north to the south, see Figure 55. It connects the village of Heesch in the south with the city centre of Oss. From the church in the centre of Oss, the route runs to the south via the Boschpoorthof and Heschepad. After the crossing with the railway, the route follows the Zonnebloemstraat, Chrysantstraat and continues via the Asterstraat and the Hescheweg to the south.

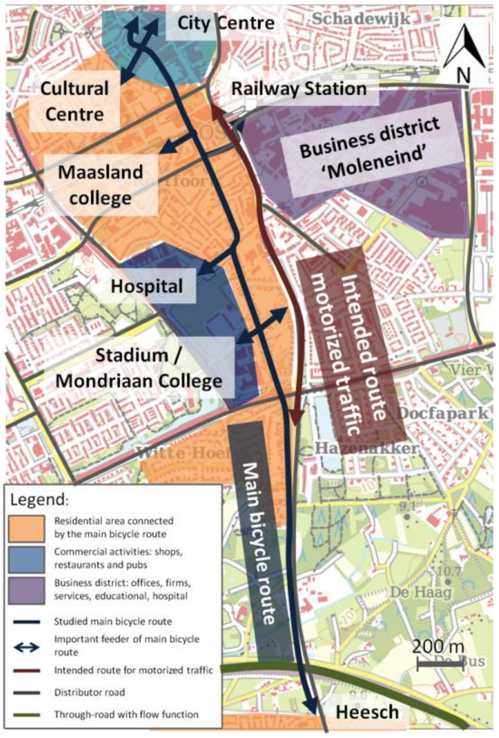

FIGURE 55: MAIN BICYCLE ROUTE BETWEEN OSS AND HEESCH

FIGURE 56: THE SINGLE-LANE BICYCLE STREET IN OSS

The main bicycle route consists of bicycle streets and bicycle paths. From the south to the north, the first part is a two-lane bicycle street, followed by a single-lane bicycle street of the road until the railway. In the last part, the route design alternates between short pieces of bicycle paths and bicycle streets.

The bicycle route connects the residential areas in Heesch and in the south of Oss with the city centre of Oss. In the city centre also facilities such as a cinema and a cultural centre are located. Halfway the bicycle street, where the applied design changes from a two-lane bicycle street to a single-lane bicycle street a hospital is located close to the bicycle street. The entrance of the hospital is not directly connected to the bicycle street, but it is an important destination for cyclists on the bicycle street. Another important destination that is not directly located along the bicycle street, but will generate a lot of bicycle traffic is a large secondary school at the southern part of the bicycle street. Here is also the stadium of FC Oss located, what will generate cycle traffic before and after football matches. At the northern part, another secondary school is located near the bicycle street.

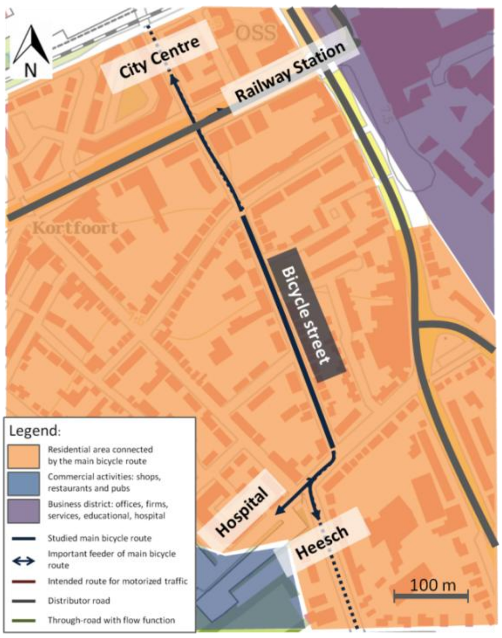

FIGURE 57: BICYCLE STREET AT THE ASTERSTRAAT IN OSS

At the northern part, the bicycle street ends at a traffic-calmed place in front of the church in the city centre. At the other side of the place, a bicycle street to Macharen, north of Oss, begins. In the south, the bicycle street ends at the end of the urban area and continues as a bidirectional cycle path along a distributor road to Heesch.

The route of the bicycle street in the Asterstraat with its origins and destinations is illustrated in Figure 57.

Urban functions

Along the Asterstraat, mainly houses are located. The urban profile is shown in Figure 56. There is a mix of different styles of houses, but all houses are older than 50 years. Some of the houses have a parking space on their own terrain, other houses don’t have a parking space on their terrain. Bicycle places have therefore been realized along the bicycle street. There is a parking ban applied to prevent cars parked on the bicycle street.

There is also a trader in furniture located along the Asterstraat. This trader does not have a store, so this will not generate large volumes of traffic. However, some freight transport by small trucks is related to this trader.

The street has a quite low building density, having detached and semi-detached houses along the street. The street has also a quite wide profile, since all the houses have a front garden. Large trees are situated on both sides of the road. The visual profile is narrowed by those trees.

Access functions

The Asterstraat is not in favour of through-going motorized traffic, since there is a distributor road parallel to the bicycle street one block away. This distributor road provides a route with the same length and higher speed and is therefore more attractive for through-going motorized traffic.

The street could provide a shorter route for traffic from the Wethouder van Eschstraat to the Hescheweg, but this shorter route has been blocked for motorized traffic in the Chrysantenstraat, north of the Asterstraat.

The houses along the Asterstraat will not generate large volumes of motorized traffic. The furniture trader will generate some freight traffic. Public transport is not using the Asterstraat.

Conclusions

The bicycle street in the Asterstraat has no unexpected conflicting functions. It is a normal access road within a traffic-calmed residential area. Only local traffic is using the Asterstraat, so the intensities of motorized traffic are quite low.

Large volumes of cyclists will be using the Asterstraat since it is part of an important bicycle route. The profile of the street fits the addressed traffic function well.

Zwolle, Vondelkade

The Vondelkade in Zwolle has been reconstructed into a bicycle street in 2003 and was one of the first bicycle streets in the Netherlands. The Vondelkade is a residential street and has been reconstructed into a single-lane bicycle street. The Vondelkade has been reconstructed into a bicycle street because of the large volumes of cyclists using the Vondelkade. In order to provide an attractive and safe route for those cyclists, the choice has been made for a bicycle street.

Flow functions

The Vondelkade is part of a main bicycle route connecting the residential area Berkum with the city centre and station of Zwolle. The route follows the Philosofenallee and Vondelkade to the Vondeltunnel and continues further via the Boerendanserdijk. Destinations other than the main destinations at the ends of the main bicycle route are the stadium of PEC Zwolle and two secondary schools in the east of Zwolle. The main bicycle route with its destinations is illustrated in Figure 58.

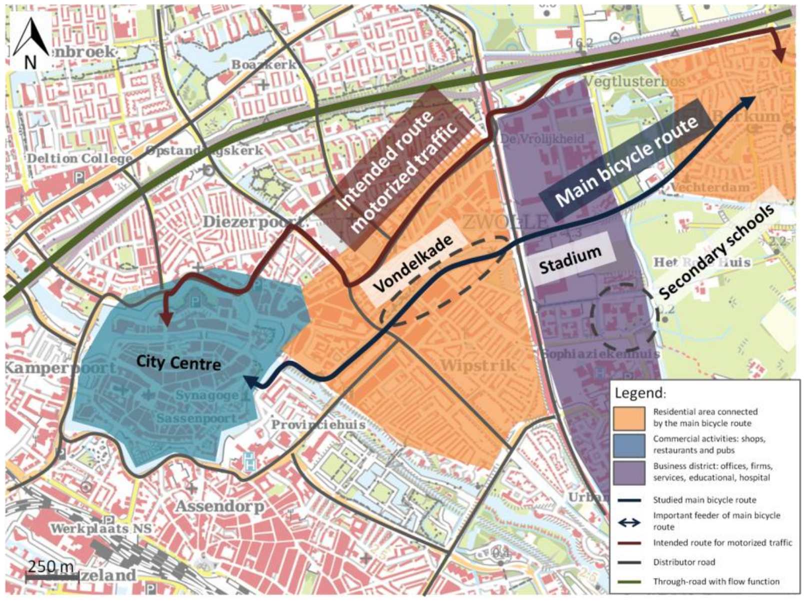

FIGURE 58: MAIN BICYCLE ROUTE IN ZWOLLE

FIGURE 59: URBAN PROFILE VONDELKADE

Various road designs are applied at the main bicycle route. The Vondelkade is a single-lane bicycle street since 2003, the Philosofenallee has recently been reconstructed in the same type of bicycle street. To the south, the main bicycle route is a residential street with bicycle lanes, continued by a bicycle street. To the north, the main bicycle route follows a distributor road with a bidirectional cycle path.

In Berkum this cycle path has some missing links and the readability and attractiveness of the bicycle route decreases. At the south, the readability of the bicycle route is better. Bicycle lanes and bicycle street designs have been applied on the route to the city centre. Towards the station, the route is less visible, only a couple of signs direct cyclists towards the station.

In the middle of the Vondelkade another bicycle route crosses the bicycle street. This bicycle route has bicycle lanes along a residential street and connects the Vondelkade and the surrounding residential areas with a commercial area and the two secondary schools in the east of Zwolle.

The bicycle street at the Vondelkade ends at one side at a bidirectional cycle path and at the other end at an intersection with a distributor road. At the other side of the distributor road, the bicycle street continues in the Philosofenallee. The intersection will be reconstructed into a bicycle roundabout to improve the traffic safety at the intersection.

Urban functions

The Vonkelkade is a traffic-calmed residential street at the outskirts of a residential area as can be seen in Figure 59. Along one side of the street houses are located, along the other side a green area and a canal are located. Those houses are typical houses from the 1930’s and have no parking spaces at their own terrain.

So, parking places have been realised along the Vondelkade to accommodate the parking demand and to prevent parking on the bicycle street. However, in the evaluation (Fietsersbond Zwolle, 2005) of the bicycle street is postulated that there is a parking problem on the bicycle street. Residents park their car with two wheels in the green area and two wheels on the bicycle street. The parked cars cause hinder for cyclists, since they are unexpected obstacles on the bicycle street.

The position of the bicycle street in the neighbourhood with the main bicycle flows illustrated by blue arrows is given in Figure 60.

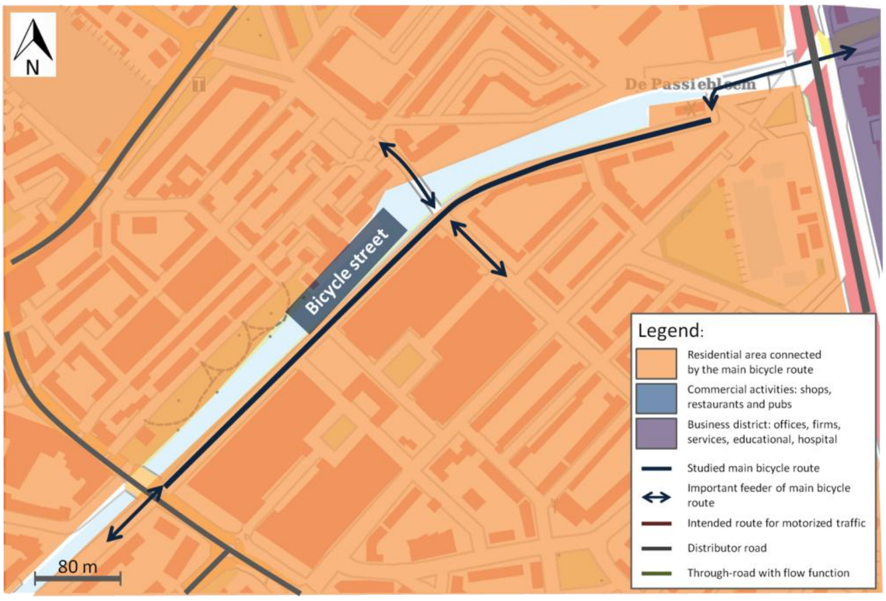

FIGURE 60: THE BICYCLE STREET AT THE VONDELKADE IN ZWOLLE

The Vondelkade has a wide profile since there are only house situated at one side of the street. At the other side of the street a large green area and a canal are located. The building density along the Vondelkade is medium low. The houses have a large front garden and the distance between the house fronts and the edge of the street is quite large. Trees along the street narrow the street visually. The profile fits the addressed function well and the speed will probably be low. However, the wide profile could provoke speeds higher than 30 km/h at quiet moments.

Access functions

The Vondelkade is a residential street, providing access to the houses along the street. One should expect a speed limit of 30 km/h at this street, however the street has a speed limit of 50 km/h, just like the other streets in the neighbourhood. The Tesselschadestraat crosses the bicycle street halfway. This street has also a speed limit of 50 km/h and traffic has priority on this street. The route Tesselschadestraat-Vondelkade is therefore an attractive route, especially since it provides a shortcut for traffic from the Ceintuurbaan to the Vechtstraat. So , too much motorized traffic is using the bicycle street, and cyclists complain that they are 'pushed' by the cars behind them (Fietsersbond Zwolle, 2005).

The attractiveness of the bicycle street is reduced by traffic measures. At the northern end, the bicycle street is a cul-de-sac for motorized traffic. At the southern end, the possible driving directions for motorized traffic are limited. Driving from the bicycle street towards the distributor road, only a right turn in the direction of the Vechtstraat is possible. From the distributor road (Vechtstraat) towards the bicycle street (Vondelkade), also only a right turn is possible. This decreases the attractiveness for motorized traffic as other streets could provide a faster route in the blocked directions.

The shortcut for motorized traffic and the traffic measures at the intersection with the Vechtstraat are illustrated in Figure 61.

FIGURE 61: SHORTCUT FOR MOTORIZED TRAFFIC VIA VONDELKADE

The houses along the Vondelkade will not generate a large volume of motorized traffic. There will also no freight transport be generated because there are no commercial activities located along the bicycle street. So, not that much heavy traffic is expected on the Vondelkade, since there are also no public transport services using the Vondelkade.

Conclusions

Based on a first function analysis, the Vondelkade appeared to be a normal bicycle street used by a small volume of motorized traffic and a large volume of cyclists. But the Vondelkade is part of shortcut for motorized traffic, causing a quite high intensity of motorized traffic on the Vondelkade. The privileged position of cyclists on the bicycle street is therefore pressured. Besides the large volume of through-going motorized traffic, are there also not enough parking spaces along the Vondelkade. Cars are therefore parked on the bicycle street, causing unexpected obstacles for cyclists.

So, the Vondelkade has some conflicting functions. The flow function for cyclists is the most important one and is supported by the bicycle street design. The motorized functions are conflicting with this flow function due to too little parking spaces and a certain amount of through-going motorized traffic. Due to this conflicting functions, conflicts could occur on the bicycle street and threaten the traffic safety on the bicycle street.

APPENDIX B: DRIVING BEHAVIOUR PER BICYCLE STREET

Per selected bicycle street, the driving behaviour has been studied by observations and road tube counters. The outcomes will be used to test six statements regarding the driving behaviour on bicycle streets. In this appendix, the outcomes will be presented per bicycle street, split up per statement.

During the observation period, notes and video recordings have been made. Those observations and video recordings have lead to qualitative descriptions of the driving behaviour on the bicycle street. In the observations has been focussed on the parking behaviour, position on the road and speed choice of cars in the neighbourhood of cyclists. Further has been focussed on whether traffic entering or crossing the bicycle street gave priority to traffic on the bicycle street.

The data that has been collected by the road tube counters provides information about the traffic intensities per vehicle category, the speeds and direction of the vehicles passing and the vehicle class, based on the number of axles of the vehicle. The producer of road tube counters states that 95% of the vehicles passing the road tube counter are recorded correctly. Vehicles driving slower than 10 km/h are not counted by a road tube counter. Road tube counters have difficulties to identify large groups of cyclists or two cyclists cycling exactly next to each other. Those will be identified as a vehicle with a lot of axles or a car with a high speed. Since those records are useless, those records have been deleted from the dataset. The vehicles with a lot of axles are identified as a separate category. All vehicles in this category have been deleted. This includes also vehicles with more than six axles passing the road tube counter. Cars with a high speed are not identified as a separate class. Therefore all vehicles with a speed higher than 80 km/h and a headway smaller than 90 seconds have been deleted from the data since those speeds are unlikely to actual occur on the bicycle street. Vehicles classified as a light motorized category with a wheel base smaller than 1.3 meters have been classified as mopeds.

The data has been collected in the period from 22nd March till 3rd April 2013. In the second weekend of the observations the Easter holiday took place. In Oss en Houten, the road tube counters were placed on 25nd March 2013 because of logistical reasons. Those measurements have therefore three weekend days and four workdays.

The bicycle streets are ordered per design. The first four bicycle streets are two-lane bicycle streets, the second four are single-lane bicycle streets.

Frieseweg, Alkmaar

Observations

The observations took place in the afternoon, around 3 p.m., since the ratio cyclists/cars is at that time around one. One could therefore expect that the chance of having conflicts between cars and cyclists is large at this time.

Information:
Tuesday 16th April 2013
Location: Frieseweg between Zaagmolenstraat and Munnikenweg
Time: 14.00 a.m. till 16.00 a.m.

The two-lane bicycle street design enforces cars more to stay behind the cyclists than the single-lane bicycle street design

The Frieseweg is a two-lane bicycle street.
Cyclists cycle at the right-hand side of their carriageway instead of in the middle of the carriageway as intended by traffic engineers. Cyclists do not pass the median to pass other, slower cyclists. Groups of cyclists, mostly students, cycle only on their own carriageway.
Cars are constantly looking for a opportunity to pass the cyclists on their carriageway. The median is no obstacle for them, and they pass the median to pass cyclists in front of them. Because cyclists are cycling on the right-hand side of their carriageway, it is possible for a car to pass cyclists while cyclists are approaching in the opposite direction. Cyclist-car-cyclist does perfectly fit next to each other in the cross-sectional profile.

Cars do not give priority to the traffic on the bicycle street when crossing or entering the bicycle street

All traffic coming from the Zaagmolenstraat to the Frieseweg has to give priority to the traffic at the Frieseweg. This has been changed with the reconstruction into a bicycle street. Before the reconstruction, traffic coming from the right had priority.
The intersection between the Frieseweg and the Zaagmolenstraat has been observed in this research. From this observation could be concluded that not all cars coming from the Zaagmolenstraat to the Frieseweg gave priority to the traffic at the bicycle street. In all cases, the car did not give priority to cyclists at the bicycle street, other traffic did always get priority.
Especially right turning traffic from the Zaagmolenstraat to the Frieseweg did sometimes take a gap that is too small. Waiting times could not be too high in those cases, because the traffic volume was not that high.

Cars parked along the bicycle street are not a large problem for the traffic safety on the bicycle street

Along the Frieseweg, only a couple of parking spots have been realized. During the observation, only one parking spot was used. Zero cars were parked on the bicycle street itself during the observation.
So, no conflicts regarding parking have been observed on the Frieseweg.
A problem related to parking that has been observed were stopping trucks and busses on the bicycle street. During the observation, a truck supplying a shop along the Frieseweg stopped on the bicycle street and drove back while cyclists are passing the truck via the other carriageway. Busses stop also on the carriageway and block the carriageway for 30 seconds or more. Cyclists and cars do not wait for the bus to depart, but pass the bus via the other carriageway.

Cars drive at the same speed as cyclists on bicycle streets

Cars do pass the cyclists on the bicycle street. From this observation could be concluded that cars drive at a higher speed than cyclists on the bicycle street. Cars on the bicycle street are constantly looking for an opportunity to pass the cyclists in front of the car.
Because most cars drive from south to north in the afternoon peak hour, they mostly have to deal with cyclists in the opposite direction and less with cars. Therefore, many cars pass the cyclists directly. Only when a large group of cyclists or a car are present in the opposite direction, cars stay behind the cyclists until the group or car has passed and there is an opportunity to pass the cyclists.
If the car driver does not have a cyclist direct in front of him, the speed is higher than when there is a cyclist in front of him.

Data

The road tube counters have been placed on the southern part of the Frieseweg. This choice has been made since this is the busiest part of the route, based on traffic counts before the reconstruction of the Frieseweg.

<u>Information</u>
Collection period: 22nd March till 3rd April 2013
Used period: 23rd March till 29th March 2013
Average weather: cold (max. 5° C), dry
Location: Frieseweg between Munnikenweg and Zaagmolenstraat
Direction A: Munnikenweg
Direction B: Zaagmolenstraat

Cars drive at the same speed as cyclists on bicycle streets

This statement has already been discussed in the observation-part. However, the data provides also information about the speed behaviour on the bicycle street and the speed choice of motorized vehicles on the bicycle street. The speeds have been plotted in a box plot in Figure 62, presenting the speeds per vehicle category.

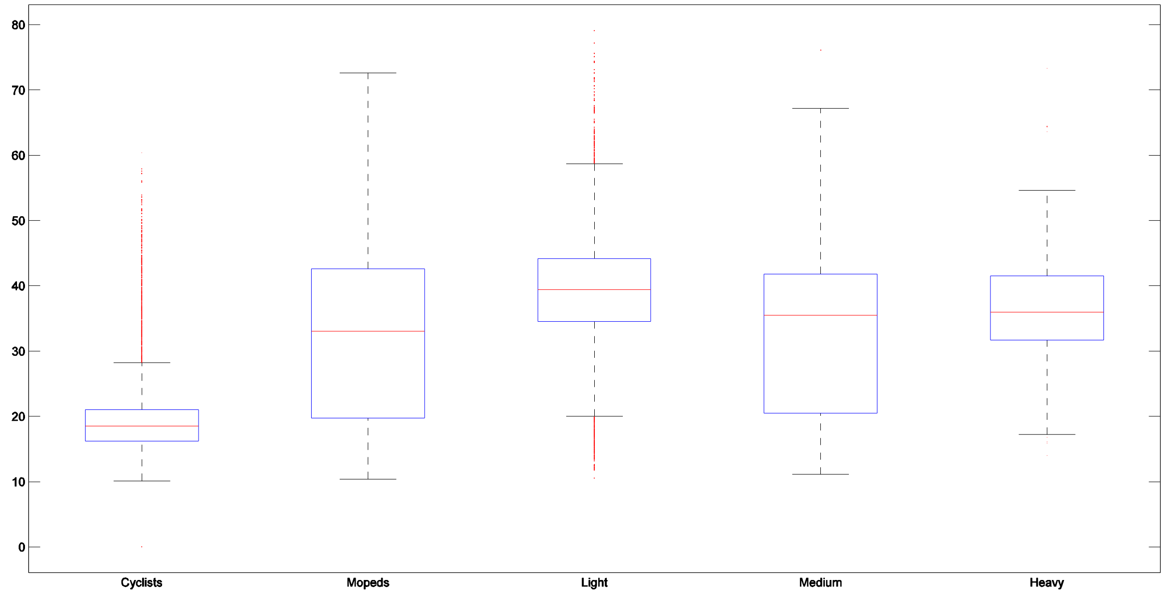

FIGURE 62: SPEEDS AT THE FRIESEWEG, PRESENTED PER VEHICLE CATEGORY

The box plot shows that the distribution and mean of the speed differ strongly per vehicle category. The speed of cyclists is concentrated around 20 km/h, while the speed of cars, in category light, is concentrated around 40 km/h. This could be considered as a large speed difference.

Another remark that could be made about the speeds, considers the speed of the categories mopeds and medium. Those two categories show a large spread of speeds. This requires a more detailed look into the speed distributions of the different classes. The speeds are therefore divided in speed classes, those are given in Figure 63.

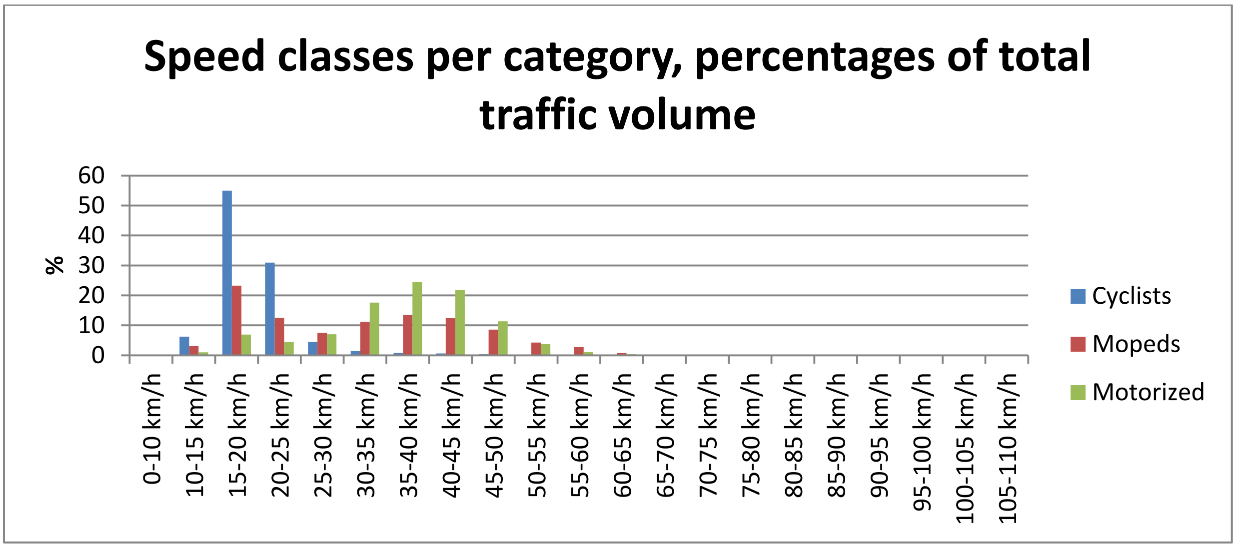

FIGURE 63: SPEED CLASSES PER CATEGORY AT THE FRIESEWEG

In Figure 63 can be seen that the speeds of cyclists are concentrated between 15 and 25 km/h. Furthermore can be seen that more than 30% of the mopeds chooses the same speed as cyclists, while also a large part chooses a speed higher than 30 km/h. As already shown in Figure 62, a large part of the motorized vehicles drives at a speed of around 40 km/h.

Speeds higher than 40 km/h are quite high for a residential street with a mixed profile. The chance to survive a crash with a motorized vehicle as a pedestrian or cyclist decreases rapidly when the speed increases (Wegman & Aarts, 2006).

There should be more cyclists than cars on the bicycle street to enforce a low speed

One would expect that drivers of motorized vehicles will choose a low speed when there are many cyclists on the street in front of the vehicle. When there are no cyclists in front of the vehicle, the driver will speed up. If this would be the case, the mean speed will vary with the ratio cyclists/motorized vehicles.

The average speeds per hour of motorized vehicles and mopeds have been plotted to the ratio cyclists/motorized. This ratio has been multiplied with 10 to make it readable. This plot is given in Figure 64.

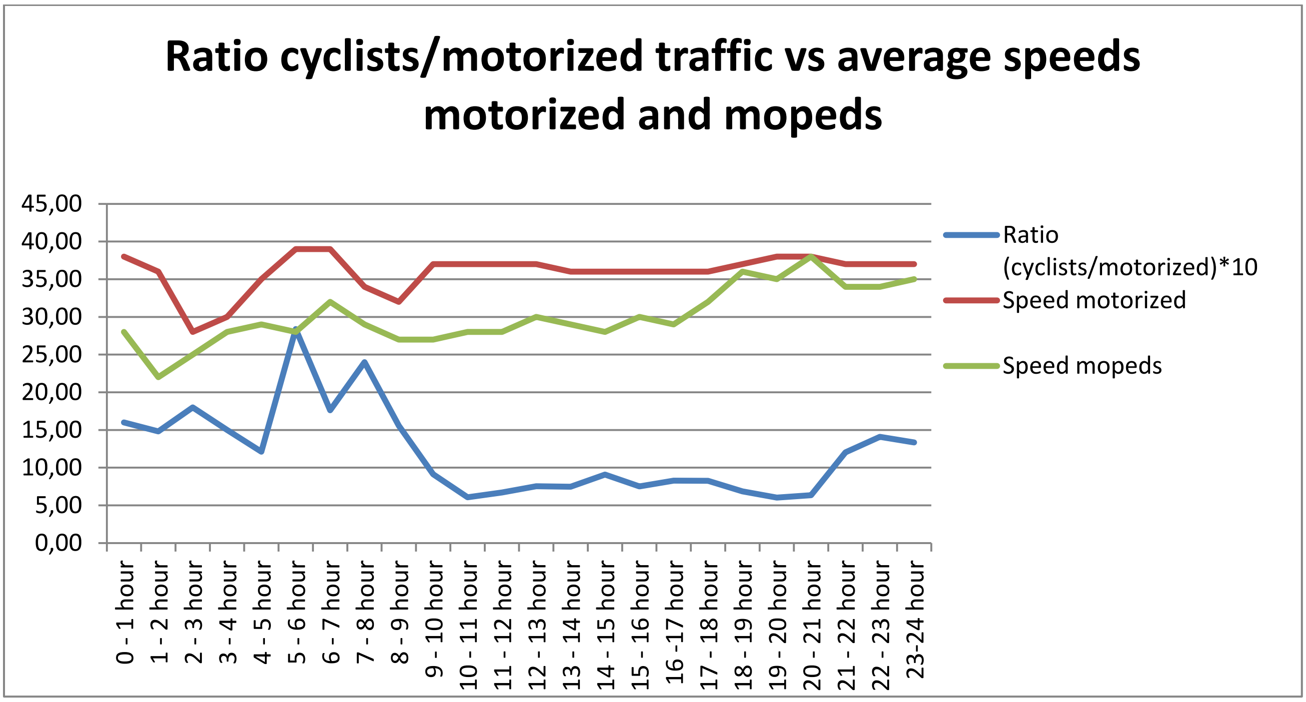

FIGURE 64: RATIO CYCLISTS/MOTORIZED VEHICLES VERSUS AVERAGE SPEEDS OF MOTORIZED VEHICLES AND MOPEDS

In Figure 64 can be seen that the ratio and speeds do mainly vary during the night. This is caused by the low intensities during the night. During some hours, only one or two vehicles have passed, setting the average speed and ratio for that hour. To clarify this, the intensities per hour are plotted in Figure 65.

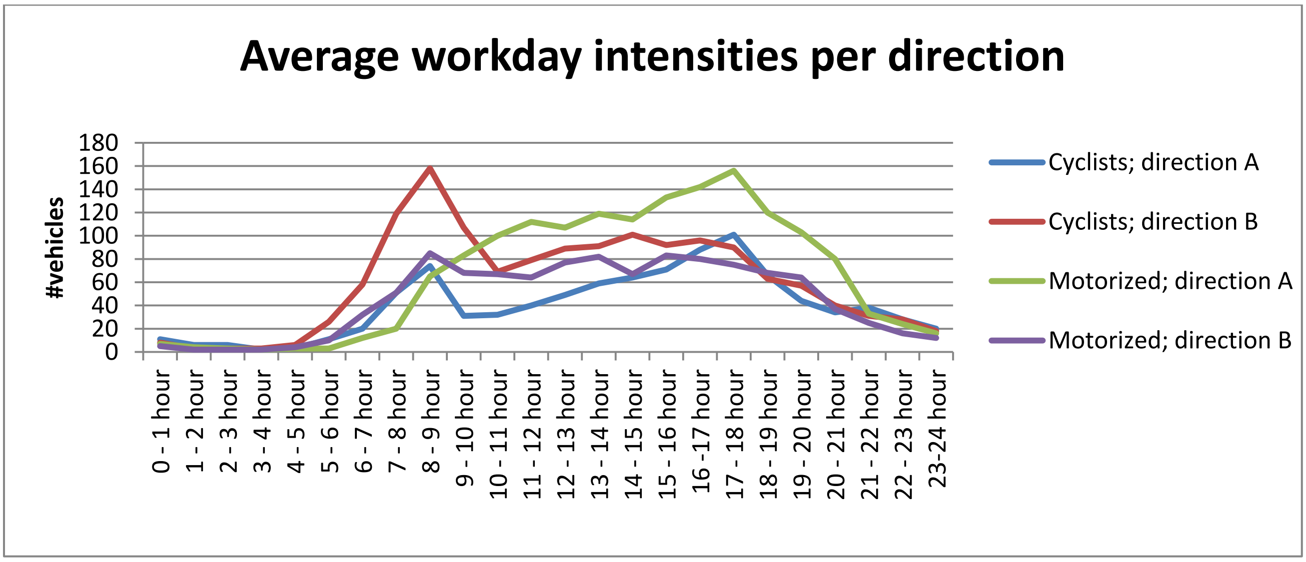

FIGURE 65: AVERAGE WORKDAY INTENSITIES PER DIRECTION

In Figure 65 can be seen that from approximately 6 a.m. enough vehicles have passed to give a good value for the average speed and ratio. If Figure 64 and Figure 65 are compared, there could be seen that from 7 a.m. till 9 a.m. the volume of cyclists is large, and the volume of motorized vehicles rather small. In this same time period, the average speed of motorized vehicles is the lowest value during the whole day (besides the inaccurate night values). So the large volume of cyclists enforces a low speed for motorized traffic. During the rest of the day, the volume of cyclists is too small compared with the large volume of motorized traffic on the Frieseweg.

To find out whether there is a correlation between the volume of cyclists and the speed of motorized vehicles, those values have been plotted in a scatter plot. This scatter plot is given in Figure 66.

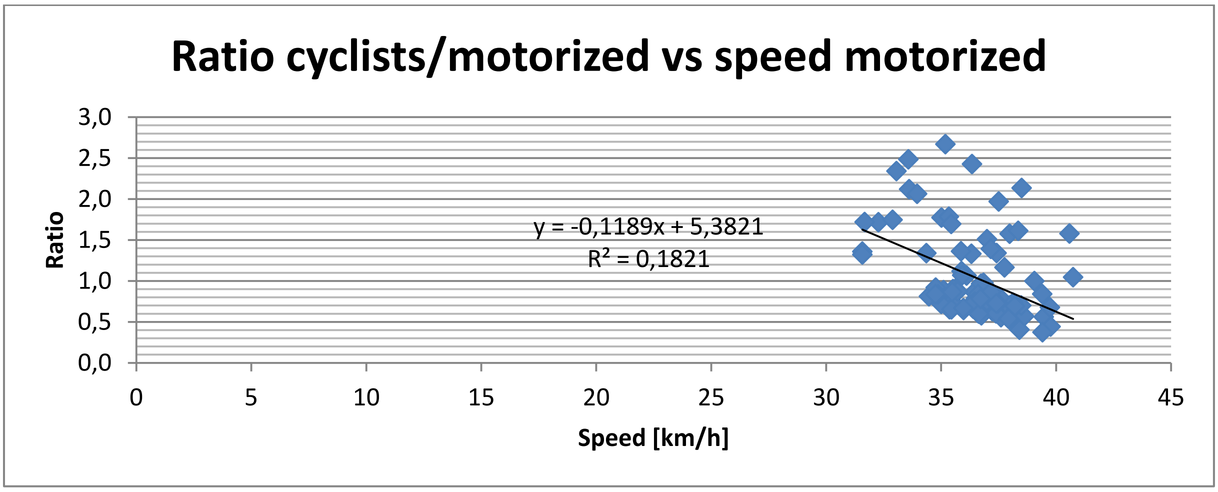

FIGURE 66: SCATTER PLOT RATIO CYCLISTS/MOTORIZED VEHICLES AND AVERAGE SPEEDS OF MOTORIZED VEHICLES

The R^2 of the trend line shows that there is a small correlation between the ratio and the average speed. This indicates that a large volume of cyclists is needed to enforce a low speed at the bicycle street.

The average speed has also been plotted versus the absolute number of cyclists on the bicycle street. This scatter plot is given in Figure 67. This plot shows a much stronger correlation between the number of cyclists on the bicycle street and the average speed at the bicycle street. The spread of data points is less than in Figure 66 and the value of R^2 is rather high.

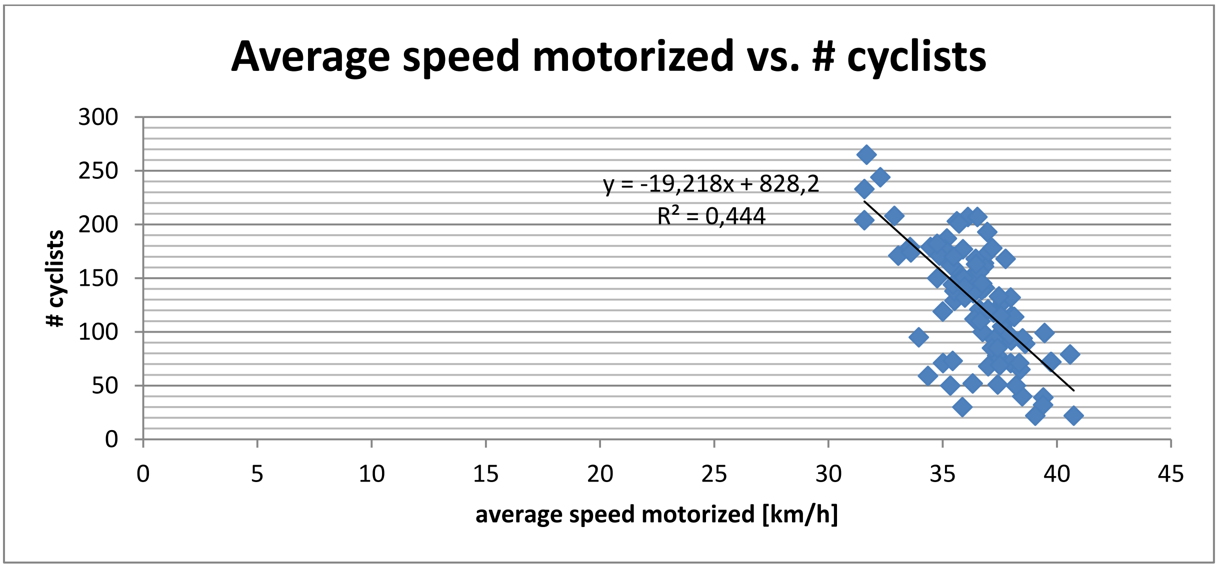

FIGURE 67: AVERAGE SPEED OF MOTORIZED VEHICLES VERSUS THE NUMBER OF CYCLISTS AT THE FRIESEWEG

Dorpsstraat, Castricum

Observations

The observations at the Dorpsstraat in Castricum took place in the morning from 9 a.m. till 11 a.m. This moment has been chosen, because the ratio cyclists/cars is between 1 and 1.5 during those hours on a Tuesday. This information has been provided by traffic counts at the Dorpsstraat.

Information:
Tuesday 16th April 2013
Location: Dorpsstraat between Schoolstraat and Torenstraat
Time: 9 a.m. till 11 a.m.

The two-lane bicycle street design enforces cars more to stay behind the cyclists than the single-lane bicycle street design

The Dorpsstraat in Castricum is a two-lane bicycle street.
Cyclists at the Dorpsstraat cycle at the right-hand side of their carriageway. Only two cyclists next to each other will use the whole carriageway for their direction. Under normal conditions, cyclists do not pass the median, even not to pass two slower cyclists next to each other. Only when the carriageway is blocked, cyclists will pass the median.
Cars are not hindered by the median. When they get the opportunity to pass cyclists, they use that opportunity. Cyclists cycling at the right-hand side of the carriageway make it possible for cars to pass without passing the median. The car will use the space of the median to pass the cyclist.

Cars do not give priority to the traffic on the bicycle street when crossing or entering the bicycle street

All the traffic entering or crossing the Dorpsstraat should give priority to the traffic at the Dorpsstraat. This was the same before the realisation of the bicycle street.
The observations have focussed on the intersection between the Dorpsstraat and the Torenstraat. This is one of the busiest intersections at the Dorpsstraat, with a lot of traffic coming from the Torenstraat to the Dorpsstraat.
While the observations were made, each car coming from the Torenstraat and entering the Dorpsstraat gave priority to the traffic at the bicycle street. A change in behaviour of the car drivers could be noticed when the waiting time became high: car drivers were willing to accept a smaller gap between cyclists, however without causing dangerous conflicts with cyclists.
Cyclists coming from the Torenstraat to the Dorpsstraat did often not give priority to the traffic at the bicycle street. In some cases, this behaviour lead to a dangerous situation since cars did not expect cyclists coming from the Torenstraat to the Dorpsstraat without giving priority.

Cars parked along the bicycle street are not a large problem for the traffic safety at the bicycle street

Parking spots have been made along the Dorpsstraat to facilitate the high parking demand caused by the shops along the Dorpsstraat. In general, these parking spots are used for short time periods, generating a lot of parking manoeuvres during the day. No conflicts between parking cars and traffic at the bicycle street have been observed.
Because cyclists cycle at the rights side of their carriageway, opened doors of parked cars could be dangerous for cyclists, but no conflicts have been observed.
Trucks supplying the shops along the Dorpsstraat did cause dangerous situations. Those trucks were parked at the carriageway and all the traffic at that carriageway had to switch to the other carriageway. Here, conflicts occur especially between cyclists switching from carriageway and cars coming in the opposite direction.

Cars drive at the same speed as cyclists on bicycle streets

If cars would drive at the same speed as cyclists, they would not pass the cyclists at the bicycle street.
The driving behaviour of car drivers as observed at the Dorpsstraat showed that car drivers use are constantly looking for a opportunity to pass cyclists. Car drivers will only drive behind cyclists and at the same speed as cyclists in two cases. In the first case, the driver has its destination directly along the bicycle street. The driver will not pass the cyclist and turn off to its destination directly afterwards, but will follow the cyclist at the speed of the cyclist. In the second case, there is too much traffic in the other direction and therefore impossible to pass the cyclist in front of the car. The driver has to adjust its speed to the cyclist.
In this second case has been observed that when a car gets the possibility to pass the cyclists in front of him, two factors determine the speed of the passing car. The first factor is the number of cyclists in front of the car, the second factor is the gap that is offered in the opposite direction. If the gap is rather small, and there is a large group of cyclists in front of the car, the speed of the car will be high to successfully pass the group of cyclists. When the gap is large and the number of cyclists low, the necessary speed to pass the cyclists successfully will be lower and the speed chosen by the car in this case is also lower. This behaviour has actually been observed at the bicycle street.

Data

The municipality of Castricum had recent traffic counts of the Dorpsstraat available. These traffic counts have been carried out with radar instead of road tube counters. This radar provides good results for motorized vehicles, but is less accurate regarding cyclists and mopeds. The radar does not differentiate in cyclists and mopeds. From the observations has been concluded that the volume of cyclists is much larger than the volume of mopeds, therefore all two-wheelers are categorized as cyclists.

<u>Information</u>
Collection period: 12th March till 26th March 2012
Used period: 13th March till 19th March 2012
Average weather: spring (max. 20° C), dry
Location: Dorpsstraat, house number 78
Direction A: Alkmaar
Direction B: Beverwijk

Cars drive at the same speed as cyclists on bicycle streets

The speeds of the different vehicle categories are presented in a box plot in Figure 68.

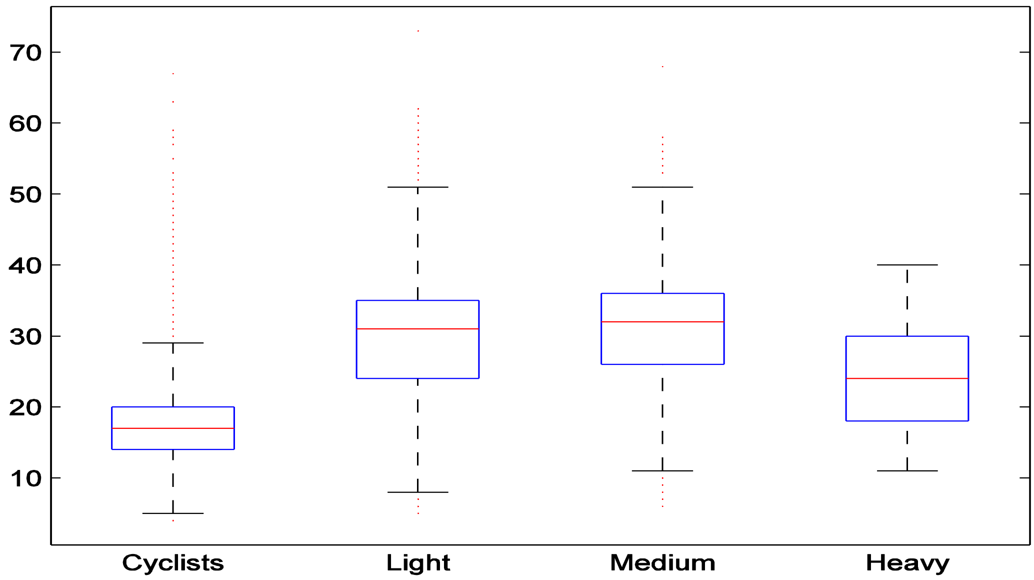

FIGURE 68: SPEEDS AT THE DORPSSTRAAT, PRESENTED PER VEHICLE CATEGORY

In Figure 68 can be seen that the speeds of cyclists differ from the speeds of the motorized vehicles. The speeds of the motorized vehicles are concentrated around 30 km/h. The speeds of vehicles in the category heavy are even lower. However, nothing is known about the speed behaviour of motorized vehicles in the neighbourhood of cyclists. Therefore a more detailed plot with categorization in speed classes is given in figure.

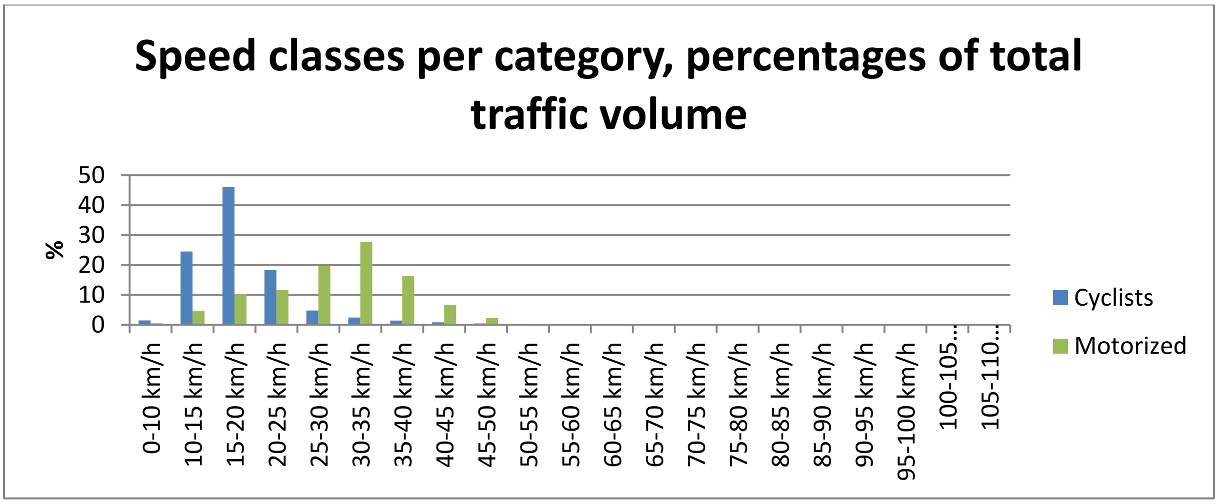

FIGURE 69: SPEED CLASSES PER CATEGORY AT THE DORPSSTRAAT

In Figure 69 can be seen that the distribution of speeds of cyclists and motorized vehicles are not the same. Most cyclists have a speed between 10 and 20 km/h, while most motorized vehicles drive at a speed between 25 and 40 km/h. The speeds of motorized vehicles are concentrated around 30 km/h. In case of a crash between a pedestrian or cyclist and a motorized vehicle, the chance to survive the crash is rather high.

There should be more cyclists than cars on the bicycle street to enforce a low speed

The volume of motorized vehicles at the bicycle street is much larger than the volume of cyclists at the bicycle street. Nevertheless is the speed of motorized vehicles at the Dorpsstraat rather low. This low speed is therefore probably not related to the presence of cyclists at the bicycle street, but the profile or presence of functions along the street. In Figure 70 the average speed per of motorized vehicles are plotted to the ratio cyclists/motorized vehicles. This ratio has been multiplied with 10 to make the speed and ratio better comparable.

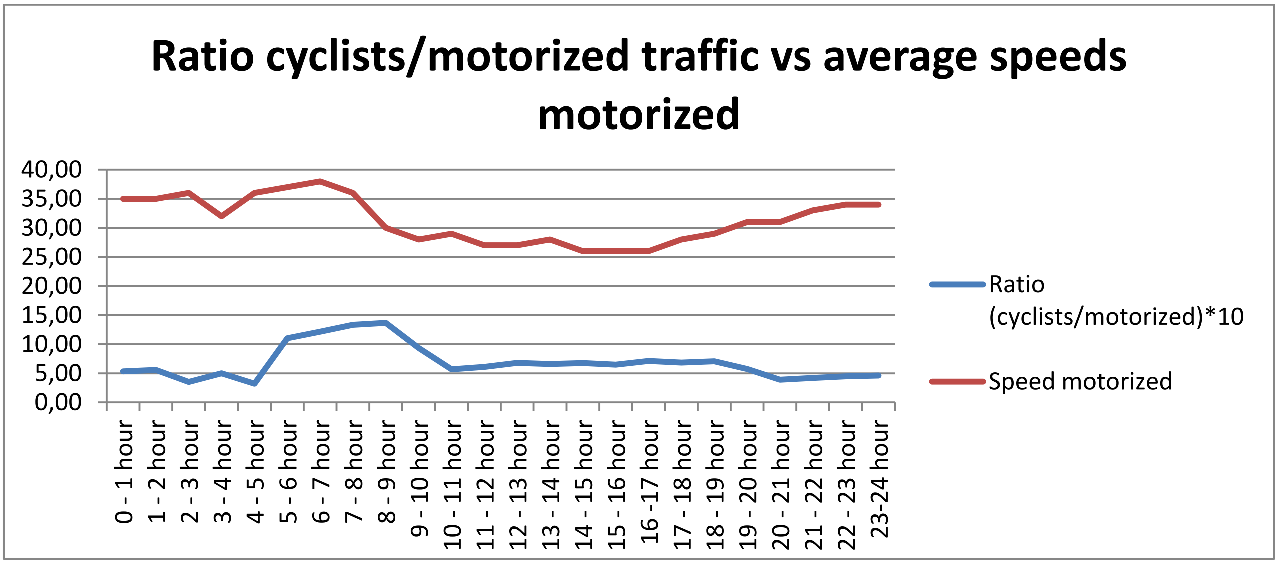

FIGURE 70: RATIO CYCLISTS/MOTORIZED VEHICLES VERSUS AVERAGE SPEED OF MOTORIZED TRAFFIC

In Figure 70 can be seen that there is no direct correlation between the speed of motorized vehicles and the ratio cyclists/motorized vehicles. The speed and ratio between midnight and 6 a.m. are not accurate enough, since only a couple of vehicles passed at that time.

The low speed is probably caused by the profile of the street and the commercial functions of the buildings along the street. The exchange function of the street is more important than the flow function for cyclists. Therefore the exchange of traffic causes probably the low speed, in combination with the narrow horizontal plane of the street.

The ratio of cyclists/motorized vehicles and the average speed have been plotted in a scatter plot to find a correlation. The scatter plot and the fitted trend line show that there is no correlation between the ratio and the average speed. The scatter plot is given in Figure 71.

The data from the hours between midnight and 6 a.m. have not been plotted in the scatter plot. The intensities are too low between those times to give a representative ratio and mean speed.

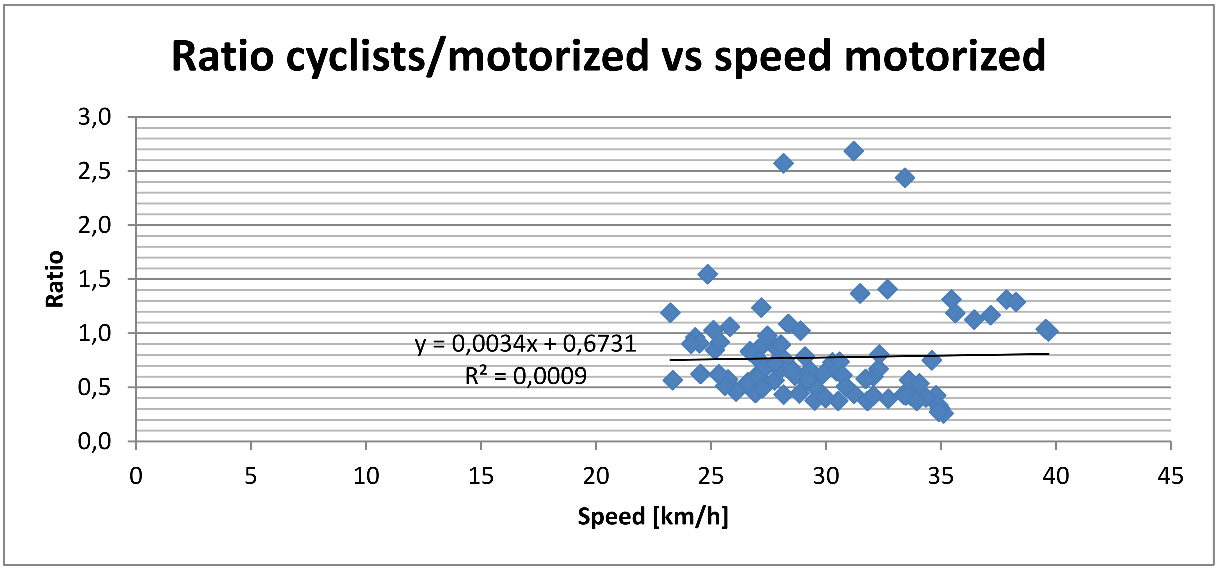

FIGURE 71: SCATTER PLOT RATIO CYCLISTS/MOTORIZED VEHICLES AND AVERAGE SPEEDS OF MOTORIZED VEHICLES

Since the ratios are small due to the large volume of motorized vehicles at the Dorpsstraat, maybe not the ratio but the absolute number of cyclists does influence the speed of motorized vehicles. Therefore, the absolute number of cyclists has been plotted versus the average speed of motorized vehicles. This scatter plot is given in Figure 72. This plot indicates that there is a relation between the number of cyclists at the bicycle street and the speed of motorized vehicles. The high value of R^2 indicates that relation is quite strong.

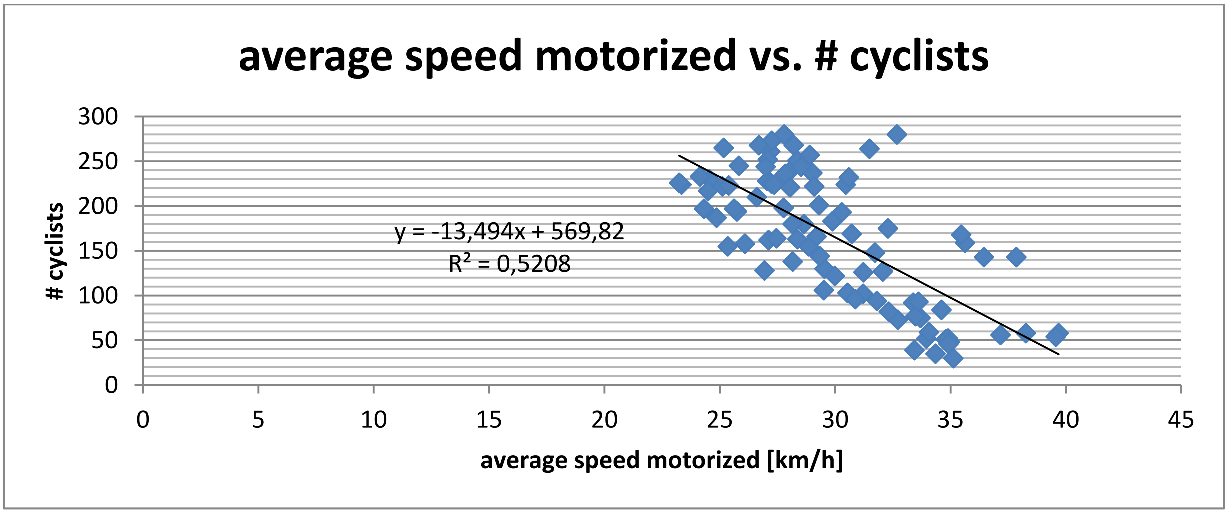

FIGURE 72: SCATTER PLOT WITH THE AVERAGE SPEED OF MOTORIZED VEHICLES AND THE NUMBER OF CYCLISTS

Ezelsveldlaan, Delft

Observations

The video recordings at the Ezelsveldlaan in Delft have been made during the morning peak hour from 8 a.m. till 9 a.m. During the morning peak hour, the ratio cyclists/motorized vehicles was 1.5. Therefore, a lot of interaction between cyclists and motorized vehicles could be seen. During the rest of the day, the ratio is larger and cyclists dominate the street.

<u>Information:</u>
Thursday 28th March 2013
Location: Ezelsveldlaan between Kruisstraat and Nieuwelaan
Time: 7.45 a.m. till 9.00 a.m.

The two-lane bicycle street design enforces cars more to stay behind the cyclists than the single-lane bicycle street design

Cars drive only at their own carriageway when there are no cyclists at their carriageway. Cars will directly pass cyclists in front of them. Many cars drive with two wheels on each side in the middle of the road, since a bicycle-car-bicycle position is possible within the cross-sectional profile.
On the one hand, cars do not hesitate to pass the median to pass a cyclist at their carriageway. On the other hand, cyclists do not leave their carriageway even not to pass slower cyclists.
Cyclists make it also easy for cars to pass, because they cycle at the right-hand side of their carriageway. A car does not necessary pass the median to pass the cyclist, but uses the width of the median to pass.

Cars do not give priority to the traffic on the bicycle street when crossing or entering the bicycle street

The bicycle street in the Ezelsveldlaan is not directly crossed by another street. However, at the end of the bicycle street, the bicycle street continues as a bidirectional cycle path. This transition takes place at the intersection with the Kruisstraat. Traffic to and from the Kruisstraat has to give priority to the cyclists. In this study, this intersection has been observed during one hour. During this hour, all vehicles crossing the bicycle street gave priority to the traffic at the bicycle street.

Cars parked along the bicycle street are not a large problem for the traffic safety at the bicycle street

Along the bicycle street a couple of parking spots have been realized. One of those spots was used during the observations. There is a safe distance between the spots and the street, so opening doors do not cause dangerous situations at the bicycle street. Besides the car parked at the parking spot, no other cars were parked or stopped at the bicycle street, being an obstacle for cyclists at the bicycle street.

Cars drive at the same speed as cyclists on bicycle streets

Since cars pass the cyclists at the bicycle street, cars will drive at a higher speed than cyclists at the bicycle street. Cars pass the cyclists immediately, mostly without adjusting their speed to the speed of the cyclists. Since only local motorized traffic is using the bicycle street, the chance of having a car in the opposite direction is rather small. Together with cyclists driving at the right-hand sides of the bicycle street, cars will drive with two wheels on each side of the median. Cyclists are less prominent in their view and so they will not adjust their speed to the cyclists. The speeds of cars are therefore rather high, compared with the speeds of the cyclists.

Data

The road tube counters have been placed in the middle of the Ezelsveldlaan. This is the part of the Ezelsveldlaan with a bicycle street lay-out.

Information
Collection period: 22nd March till 3rd April 2013
Used period: 23rd March till 29th March 2013
Average weather: cold (max. 5° C), dry
Location: Ezelsveldlaan between Kruisstraat and Nieuwelaan
Direction A: Kruisstraat
Direction B: Nieuwelaan

Cars drive at the same speed as cyclists on bicycle streets

An overview of the speeds driven at the bicycle street in Delft is given in the box plot in Figure 73.

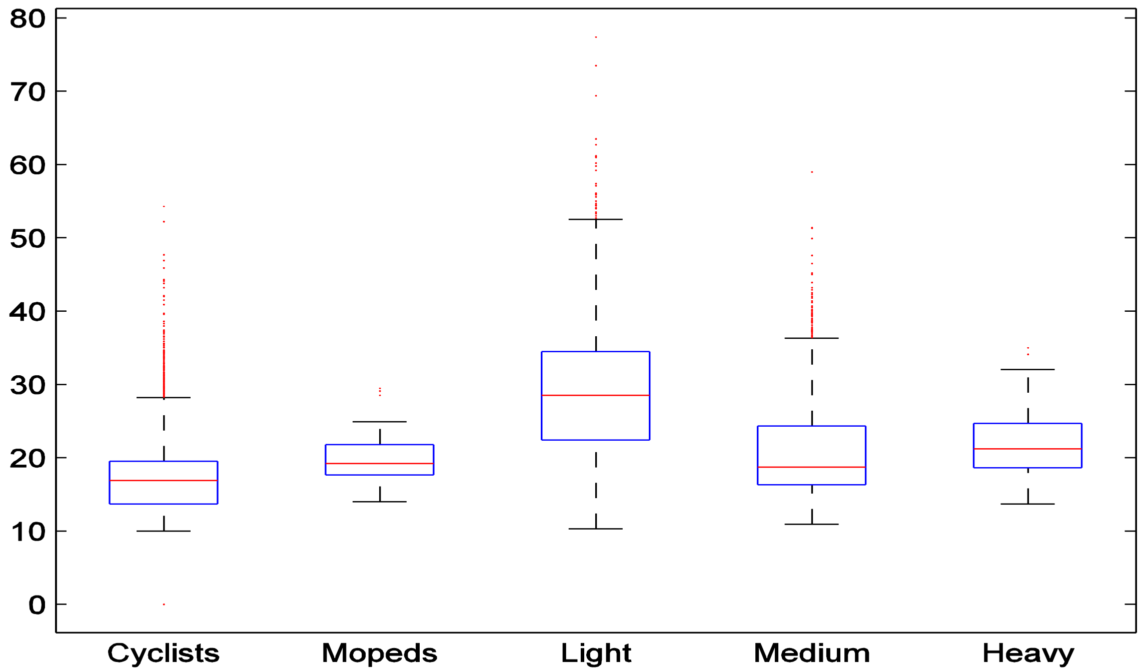

FIGURE 73: SPEEDS AT THE EZELSVELDLAAN, PRESENTED PER VEHICLE CATEGORY

In Figure 73 can be seen that the speeds of cars are concentrated around 30 km/h. The speeds of the other categories are concentrated around 20 km/h. The speeds have also been split up in speed classes to provide a more detailed look on the speeds at the bicycle street. Those speed classes are given in Figure 74

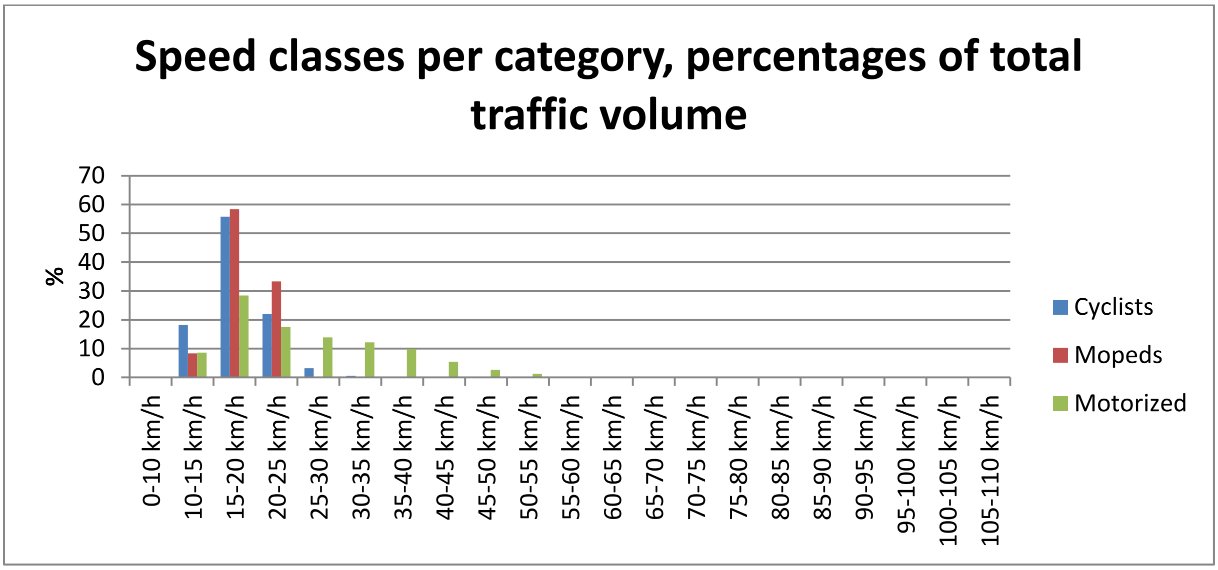

FIGURE 74: SPEED CLASSES PER CATEGORY AT THE EZELSVELDLAAN

In Figure 74 can be seen that the speeds of cyclists and mopeds are concentrated between 15 and 25 km/h. The speeds of motorized vehicles are concentrated between 15 and 30 km/h, with a large part below 25 km/h. Those are considered as safe speeds, since the chance a pedestrian or cyclist survives a crash with a motorized vehicle at that speed is large.

There should be more cyclists than cars on the bicycle street to enforce a low speed

The speeds of motorized vehicles at the bicycle street are low. This low speeds could be caused by the large volume of cyclists at the bicycle street or by other factors such as the profile or horizontal plane of the street. In order to find out whether the large volume of cyclists or other factors play a role, the average speed of motorized vehicles and mopeds have been plotted together with the average ratio cyclists/motorized vehicles.

The average speed of mopeds is not very representative, since the volume of mopeds at the bicycle street is very low. In some hours, no moped passed and therefore the average speed is zero.

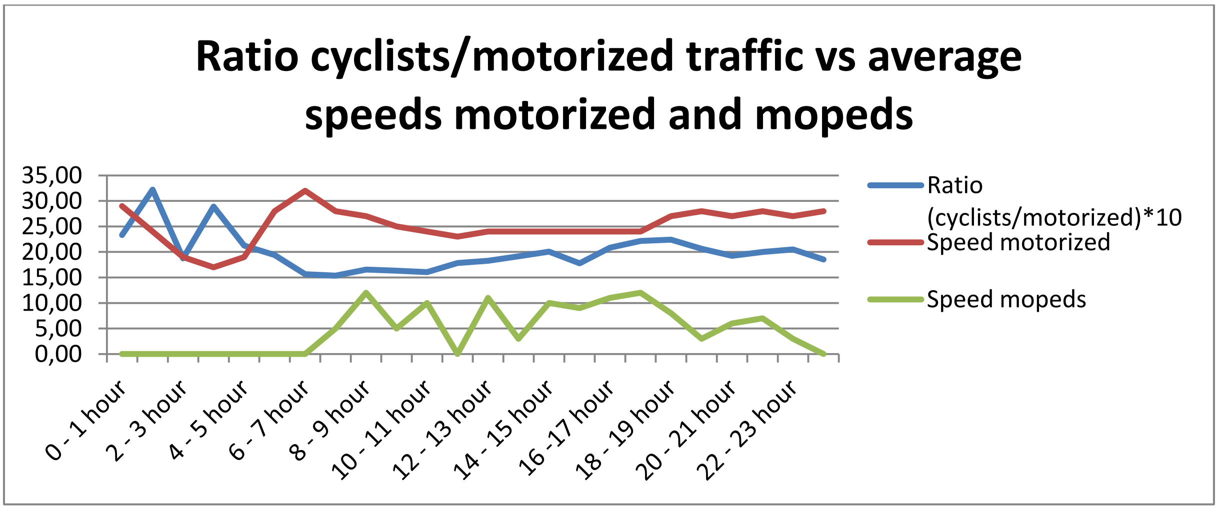

FIGURE 75: RATIO CYCLISTS/MOTORIZED VEHICLES VERSUS THE AVERAGE SPEED OF MOTORIZED VEHICLES AND MOPEDS

In Figure 75 the average speed and ratio are given. In the plot can be seen that the speed of mopeds fluctuates due to the low intensities. Also between midnight and 6 a.m. not enough vehicles passed to give a good representation of the average speed and the ratio cyclists/motorized vehicles. However, in Figure 75 can be seen that the average speed decreases from 6 a.m. till noon, while the ratio increases. In the evening, the ratio decreases and the average speed increases. So there is an indication that the average speed is related to the ratio cyclists/motorized vehicles.

To find out whether there is a correlation between the speed of motorized vehicles and volume of cyclists at the bicycle street, the ratio cyclists/motorized has been plotted versus the average speed in a scatter plot. This scatter plot is given in Figure 76.

The data from the hours from midnight till 6 a.m. have been deleted, because they are not representative for the behaviour at the bicycle street due to the low intensities at those times.

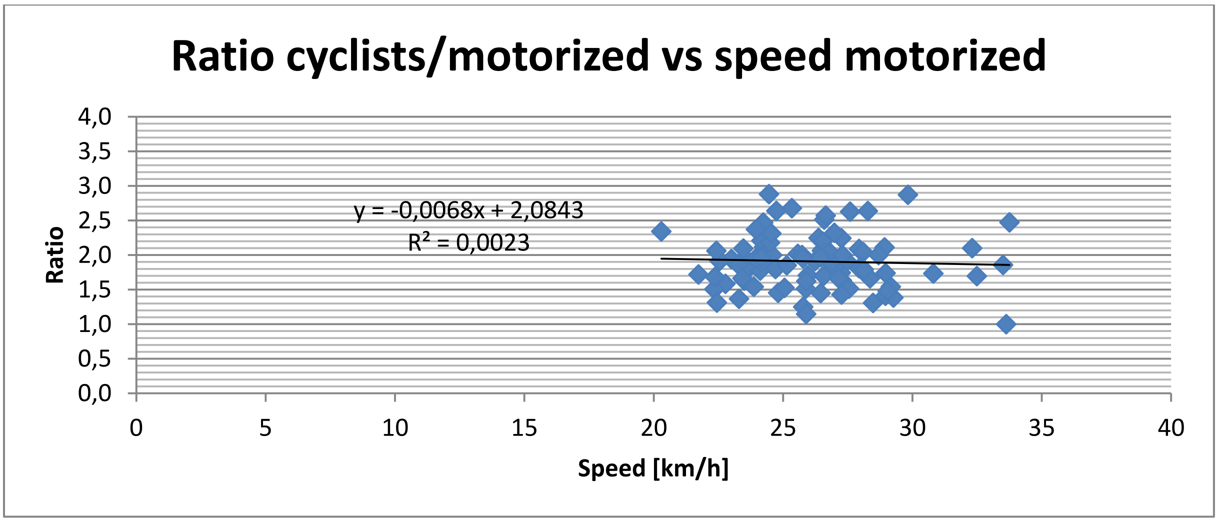

FIGURE 76: SCATTER PLOT WITH THE RATIO CYCLISTS/MOTORIZED VERSUS THE AVERAGE SPEED OF MOTORIZED VEHICLES

Figure 76 shows that there is no correlation between the ratio cyclists/motorized vehicles and the average speed of motorized vehicles. So the low speed at the bicycle street is probably caused by other factors than the volume of cyclists at the bicycle street.

Since there is no relation between the ratio and the average speed, the absolute number of cyclists has been plotted versus the average speed of motorized vehicles in Figure 77. This plot shows that there is a relation between the number of cyclists and the average speed of motorized vehicles. This relation is also quite strong, since the value of R^2 is rather high.

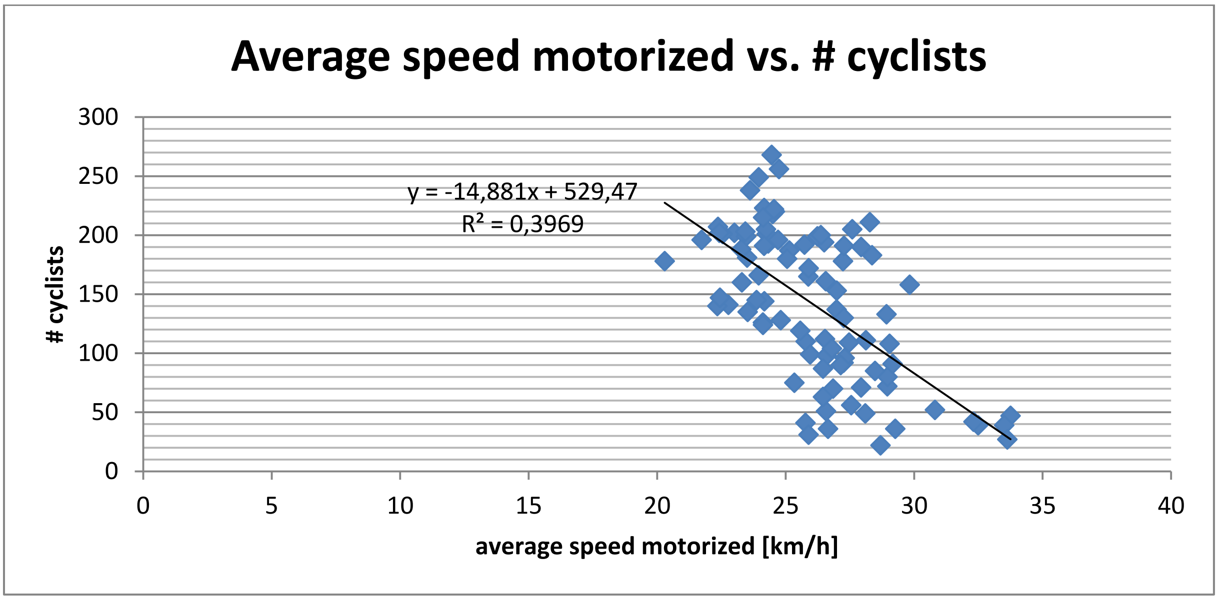

FIGURE 77: AVERAGE SPEED OF MOTORIZED VEHICLES VERSUS THE NUMBER OF CYCLISTS

Zegwaartseweg, Zoetermeer

Observations

Traffic at the Zegwaartseweg has been observed in the morning, between 9.30 a.m. and 11.15 a.m. During this period, many students passed, since the bicycle street is part of an important route between residential areas and several secondary schools.

Information:
Wednesday 10th April 2013
Location: Zegwaartseweg, intersection with Marconistraat/Dadelgaarde
Time: 9.30 a.m. till 11.15 a.m.

The two-lane bicycle street design enforces cars more to stay behind the cyclists than the single-lane bicycle street design

The Zegwaartseweg is a two-lane bicycle street.
There are not that many cars at the bicycle street, since only local traffic is using the bicycle street. The cars that are driving at the bicycle street, mostly drive with two wheels on each side of the median. The chance that there is a car in the opposite direction is rather small and by driving in the middle of the street, a bicycle-car-bicycle position is possible in the cross-sectional profile. If there is a large group of cyclists approaching in the opposite direction, cars stay at their own carriageway behind the cyclists.
The median does enforce cyclists to stay at their own carriageway. Only one group of students at the bike did use the whole width of the bicycle street.

Cars do not give priority to the traffic on the bicycle street when crossing or entering the bicycle street

In this study, the intersection between the Zegwaartseweg and the Marconistraat/Dadelgaarde has been observed. Traffic at the Marconistraat/Dadelgaarde should give priority to traffic at the bicycle street. There is a stop line and several traffic signs accentuate that traffic at the Marconistraat/Dadelgaarde should give priority. A high speed bump just before the intersection enforces a low speed.

The result of all those traffic measures is that cars approach the intersection with a very low speed and give priority to all the traffic at the Zegwaartseweg, even pedestrians. This caused also the only conflict that has been observed during the observations: one car gave priority to a pedestrian at the bicycle street, while a car in the other direction did not give priority to the pedestrian. The pedestrian does not have priority at the intersection.
Remarkable was that cyclists at the Marconistraat/Dadelgaarde did almost never give priority to the traffic at the bicycle street.

Cars parked along the bicycle street are not a large problem for the traffic safety at the bicycle street

There are no parking spots along the bicycle street. Cars are parked at the carriageway of the bicycle street. The parked cars are obstacles for cyclists at the bicycle street, since they are parked at their carriageway. Opened doors of cars could even block the whole street, since the dimensions of the bicycle street are rather small.
Parked cars at the bicycle street are problem for the traffic safety at this bicycle street.

Cars drive at the same speed as cyclists on bicycle streets

The speeds of cars at the bicycle street are low and do not differ that much from the speeds of cyclists. This is caused by speed bumps in the bicycle street, every 80 meters. But also the small amount of cars does play a role. A car at the bicycle street does only have to anticipate on the cyclists at the street. If a car does pass cyclists, the gap is often that large that also at a low speed the cyclists could be passed.

Data

The road tube counters have been placed on the stretch between the Marconistraat and the Van der Hagenstraat. There is a cut for motorized traffic halfway this stretch. The road tube counters have been placed on the northern part of the stretch, near the Marconistraat.

Information
Collection period: 22nd March till 3rd April 2013
Used period: 23rd March till 29th March 2013
Average weather: cold (max. 5° C), dry
Location: Zegwaartseweg between Marconistraat and Van der Hagenstraat
Direction A: Van der Hagenstraat
Direction B: Marconistraat

Cars drive at the same speed as cyclists on bicycle streets

Figure 78 shows the measured speeds on the bicycle street per vehicle category in a box plot. In the box plot could be seen that the speeds of cyclists are concentrated around 20 km/h. The speeds of cars are concentrated around 30 km/h, while the speeds of vehicles with a medium weight are concentrated around 15 km/h. Only a few heavy vehicles have passed at the bicycle street, therefore there is not a wide distribution of speeds of heavy vehicles.

The mean speed of the mopeds is rather high and the variance in speeds of mopeds is large. Those fast driving mopeds could be a threat for the traffic safety on the bicycle street.

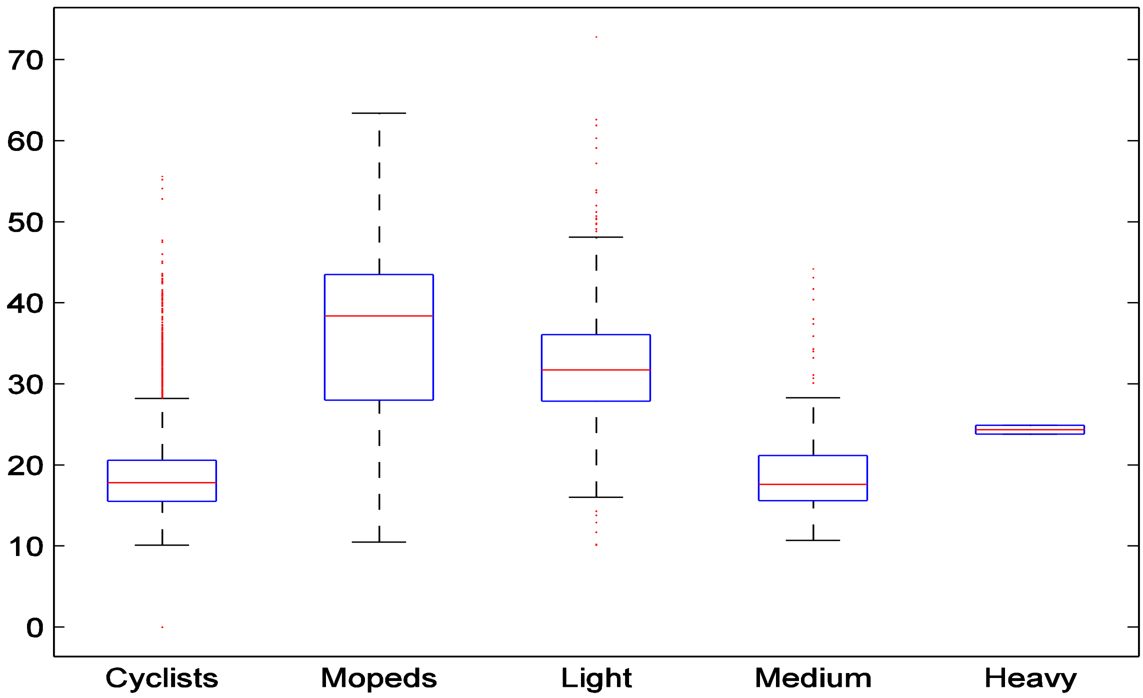

FIGURE 78: SPEEDS AT THE ZEGWAARTSEWEG, PRESENTED PER VEHICLE CATEGORY

A more detailed look at the speeds is provided by dividing the speeds in speed classes per vehicle category. Those speed classes are given in Figure 79.

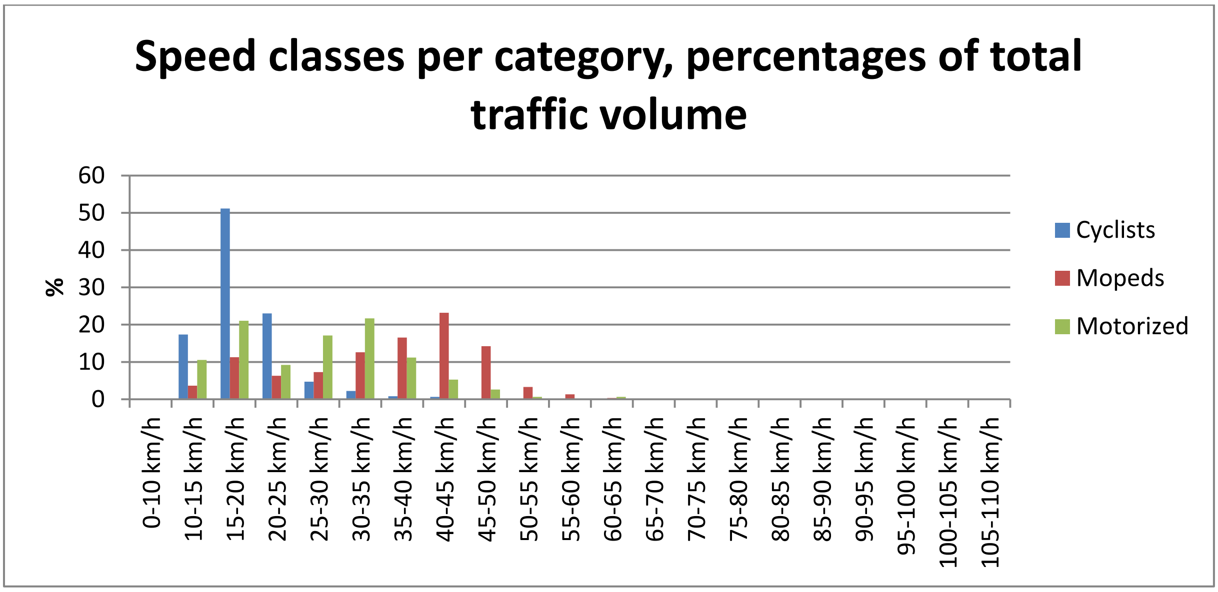

FIGURE 79: SPEED CLASSES PER CATEGORY AT THE ZEGWAARTSEWEG

In Figure 79 can be seen that the speeds of cyclists are concentrated between 15 and 25 km/h. In the category motorized vehicles can be seen that there are two peaks, one around 20 km/h and the other between 25 and 35 km/h. The first peak contains mainly the speeds of the vehicles in the category medium, while the second peak contains mainly the speeds of the vehicles in the category light.

Remarkable are the high speed of mopeds on the bicycle street. More than 50 percent of the mopeds drives at a speed faster than 35 km/h at the bicycle street. This results in a large speed difference between mopeds and cyclists.

The speeds of cars could be considered as safe, but the speed difference between mopeds and cyclists is rather high at this bicycle street.

There should be more cyclists than cars on the bicycle street to enforce a low speed

The volume of cyclists at the bicycle street is much larger than the volume of motorized vehicles at the bicycle street. The speeds of cars at the bicycle street are not too high, so the large volume of cyclists could have enforced a low speed. However, other factors could also lead to a low speed. To find out whether the low speed depends on the large volumes of cyclists at the bicycle street, the average speed of motorized vehicles has been plotted to the ratio cyclists/motorized vehicles. The plot is shown in Figure 80.

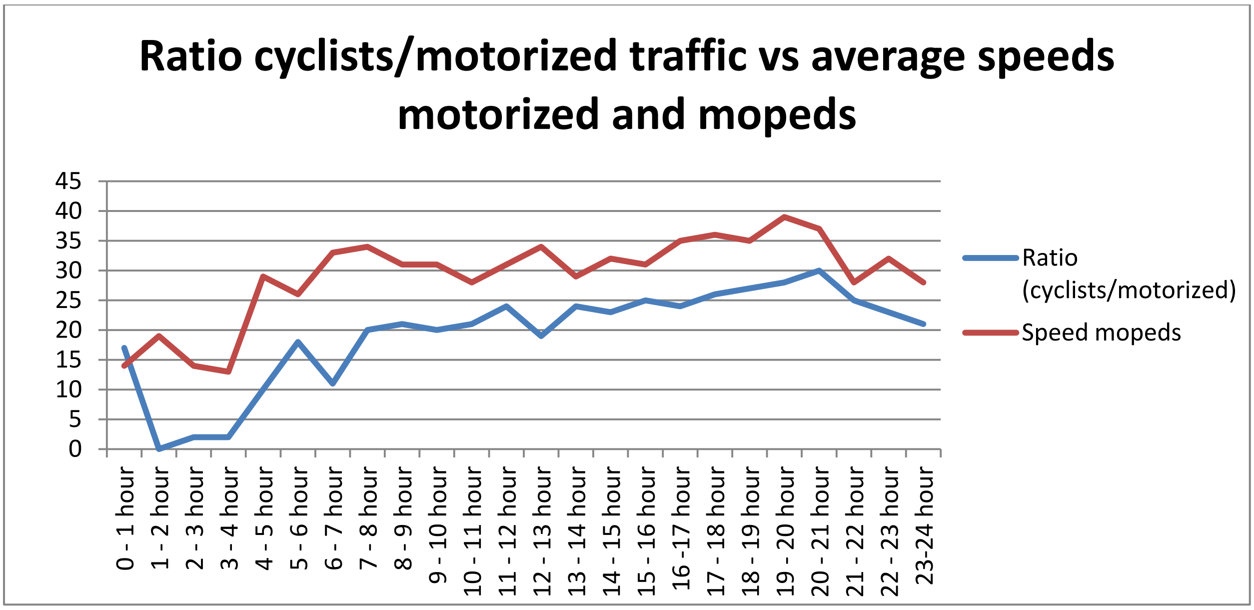

FIGURE 80: RATIO CYCLISTS/MOTORIZED VEHICLES VERSUS AVERAGE SPEED OF MOTORIZED VEHICLES AND MOPEDS

From midnight till 6 a.m., too less vehicles have passed to calculate a representative average speed and ratio. In Figure 80 can be seen that there is an indication for a relation between the ratio cyclists/motorized and the average speed of the motorized traffic at the bicycle street. Between 6 and 7 a.m. there is a dip in the speed, while there is peak in the ratio. Then, the ratio decreases and the speed increases. Between 12 and 13 hour there is a peak in the ratio and a typical dip in the speed. After 13 hour, the ratio decreases, while the speed increases.

The ratio and average speed have also been plotted in a scatter plot. Data between midnight and 6 a.m. has been deleted, since the values are not representative due to the low intensities between those times. The scatter plot is given in Figure 81.

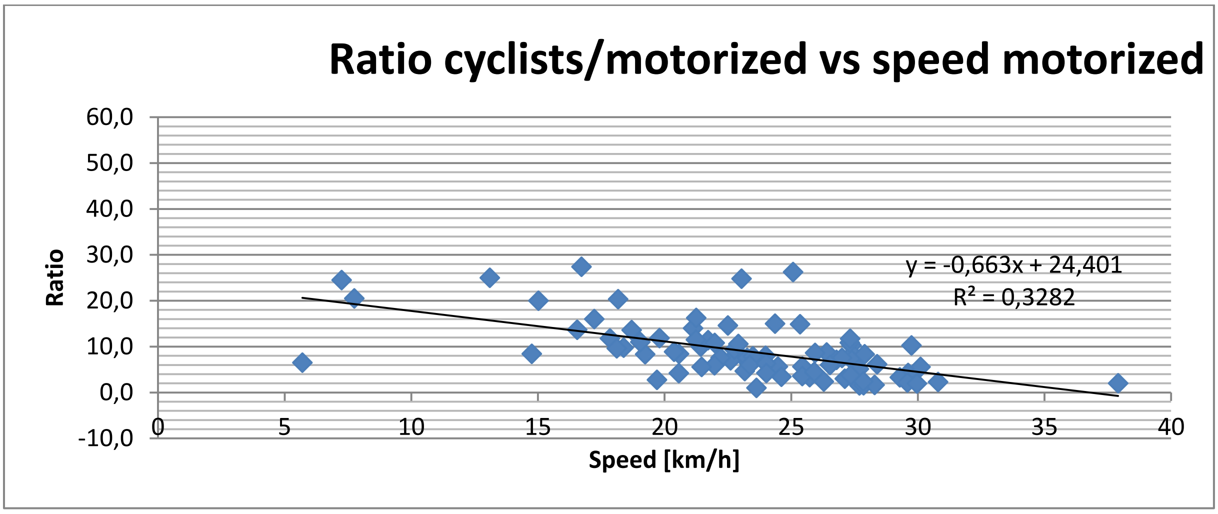

FIGURE 81: SCATTER PLOT WITH THE RATIO CYCLISTS/MOTORIZED VERSUS THE SPEED OF MOTORIZED VEHICLES

The trend line in Figure 81 shows that there is indeed a correlation between the ratio cyclists/motorized and the speed of motorized vehicles at the bicycle street. The R^2 is quite high, indicating that the correlation is quite strong.

Venkelstraat, Haarlem

Observations

Traffic at the Venkelstraat has been observed during the morning peak hour. This is the leading hour regarding the traffic intensities of both cyclists and motorized traffic. Figure 82 shows the intensities during the day, it is clear that the morning peak is the leading peak hour.

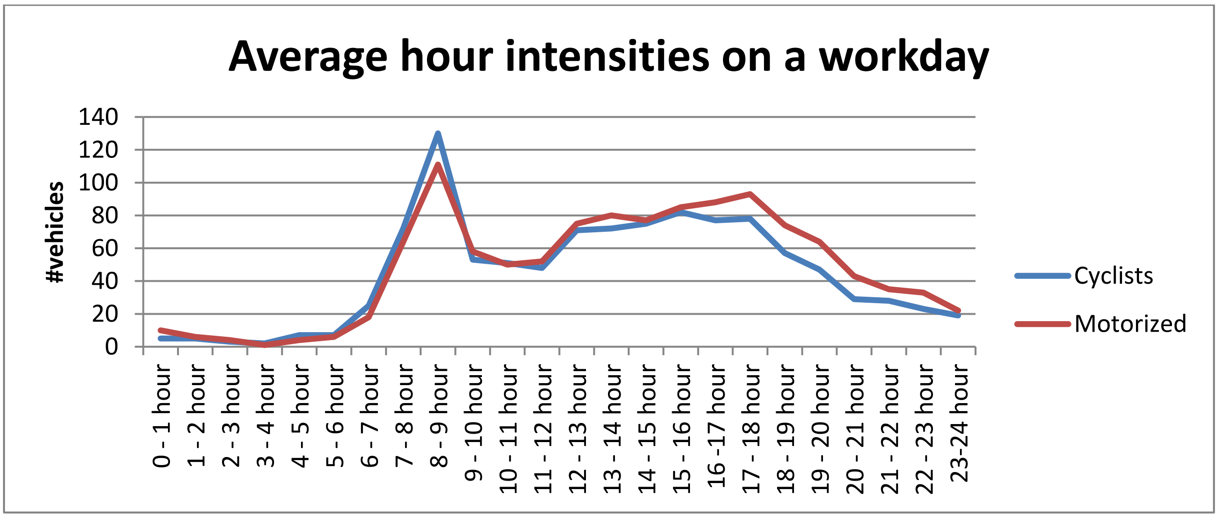

FIGURE 82: AVERAGE HOUR INTENSITIES AT THE VENKELSTRAAT

Information:
Thursday 18th April 2013
Location: Venkelstraat, intersection with Anijsstraat
Time: 7.40 a.m. till 9.00 a.m.

The two-lane bicycle street design enforces cars more to stay behind the cyclists than the single-lane bicycle street design

The Venkelstraat is a single-lane bicycle street.
The bicycle street has a lane line in the middle of the road, indicating the two lanes for cyclists. Due to this separation, most cyclists stay at their own lane. Cars behind the cyclists can only pass the cyclists in front of the car when there is no traffic in the opposite direction. Many cyclists are cycling at the rabat strip instead of the asphalt carriageway. This makes it possible for cars to pass cyclists by riding at the asphalt carriageway. Cyclists have a less prominent position at the street when cycling at the rabat strips. The speed of cars passing cyclists at the rabat strip seems to be higher than when passing cyclists cycling at the asphalt strip.
If there are large groups of cyclists are present at the bicycle street, in this case before the opening time of the school, cars stay behind the cyclists and do not pass. When there is little traffic present at the bicycle street, cars will pass the cyclist, but due to its position at the middle of the road and the small dimensions, the car will have to pass at a low speed.

Cars do not give priority to the traffic on the bicycle street when crossing or entering the bicycle street

The bicycle street has priority at all intersections. In this research, the intersection with the Anijsstraat has been observed. During the observation, all traffic coming from the Anijsstraat gave priority to the traffic at the bicycle street.

Cars parked along the bicycle street are not a large problem for the traffic safety at the bicycle street

Along the bicycle street, several parking spots have been realized, perpendicular to the street. During the observations, one car was parked in a parking spot. This happened at a quiet moment at the bicycle street, without generating conflicts with other traffic at the bicycle street. Zero cars were parked at the carriageway of the bicycle street. Furthermore, no vehicles stopped at the street.

Cars drive at the same speed as cyclists on bicycle streets

The cars that passed during the observation period passed at a low speed. Partially caused by the speed bumps in the bicycle street, but for a large part caused by the prominent position of cyclists at the bicycle street. Cars anticipate on the presence of cyclists at the street.
Cars drive faster when there are no cyclists at the bicycle street.

Data

The road tube counters have been placed at the stretch between the Karwijpad and the Anijsstraat. This stretch has been chosen since it is a central part of the bicycle street.

Information
Collection period: 22nd March till 3rd April 2013
Used period: 23rd March till 29th March 2013
Average weather: cold (max. 5° C), dry
Location: Venkelstraat between Karwijpad and Anijsstraat
Direction A: Karwijpad
Direction B: Anijsstraat

Cars drive at the same speed as cyclists on bicycle streets

The speeds that are driven at the bicycle street are presented in a box plot, showing the mean and variation of the speeds. The speeds have been split up in different vehicle categories. The box plot is given in Figure 83.

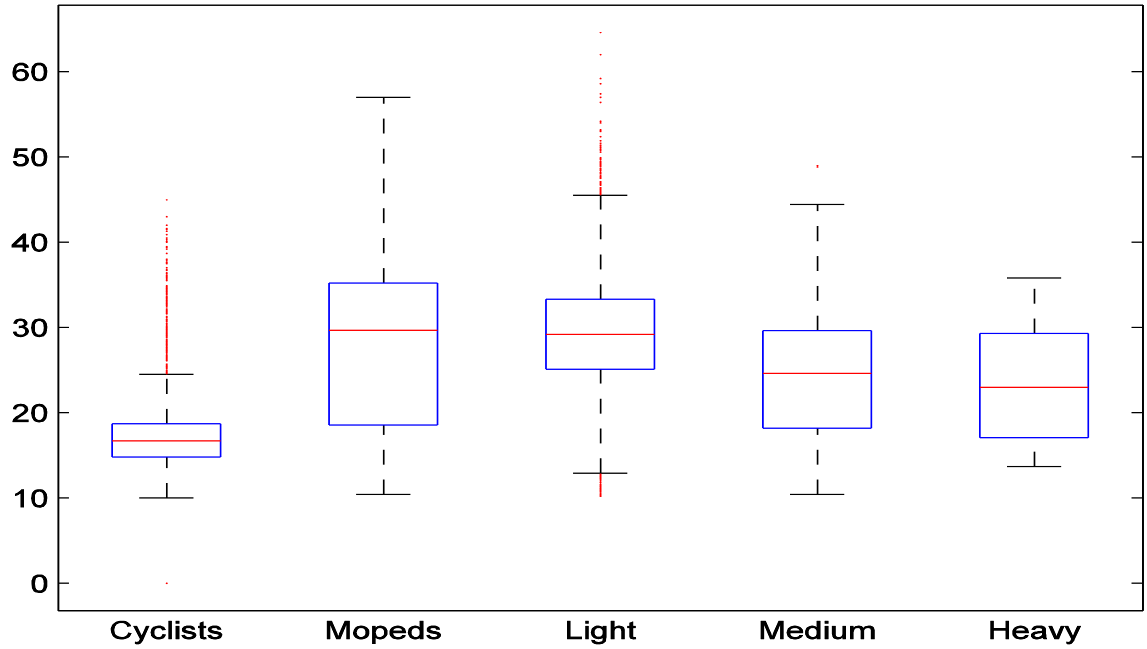

FIGURE 83: BOX PLOT PRESENTING THE SPEEDS AT THE VENKELSTRAAT PER VEHICLE CATEGORY

In Figure 83 can be seen that the speeds of cyclists are concentrated at 17 km/h, while the speeds of mopeds and light motorized vehicles are concentrated around 30 km/h. The variance in the speeds of the mopeds is large. The speeds of medium and heavy motorized vehicles are lower and the variance in speeds is much smaller.

A more detailed look on the speeds is provided by a plot of the different speed classes in Figure 84.

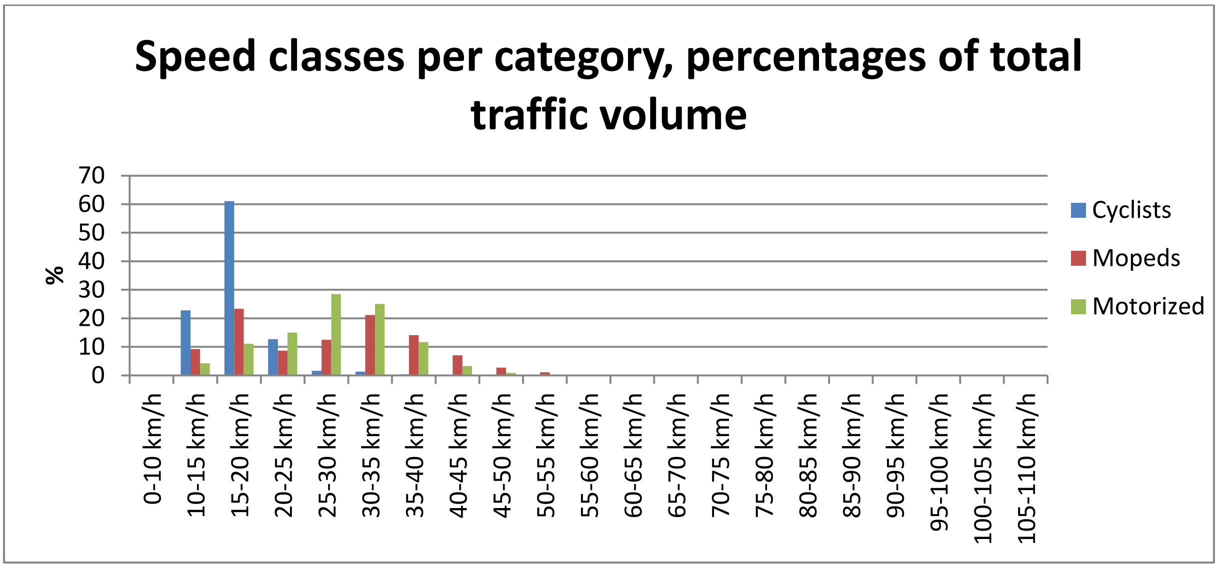

FIGURE 84: SPEED CLASSES PER CATEGORY AT THE VENKELSTRAAT

Figure 84 shows that the speeds of cyclists are concentrated between 10 and 20 km/h. The speeds of mopeds have two peaks, one between 15 and 20 km/h and one between 30 and 35 km/h. The speeds of cars are concentrated between 25 and 35 km/h. Considering those outcomes could be concluded that most cars do not drive at the same speed as cyclists, but that the speeds of both mopeds and motorized traffic are not high.

There should be more cyclists than cars on the bicycle street to enforce a low speed

In Figure 85, the average speeds of mopeds and motorized vehicles are plotted together with the ratio cyclists/motorized vehicles. The values of the average speed and ratio between midnight and 6 a.m. are not representative due to the low intensities between those times. The average speed of motorized vehicles is quite constant over the day, except of one dip between 8 and 9 a.m. This is the leading peak hour. During this hour, on average 130 cyclists pass by, together with 110 motorized vehicles. So the ratio is not that high at that moment, but in absolute numbers are there many cyclists on the bicycle street.

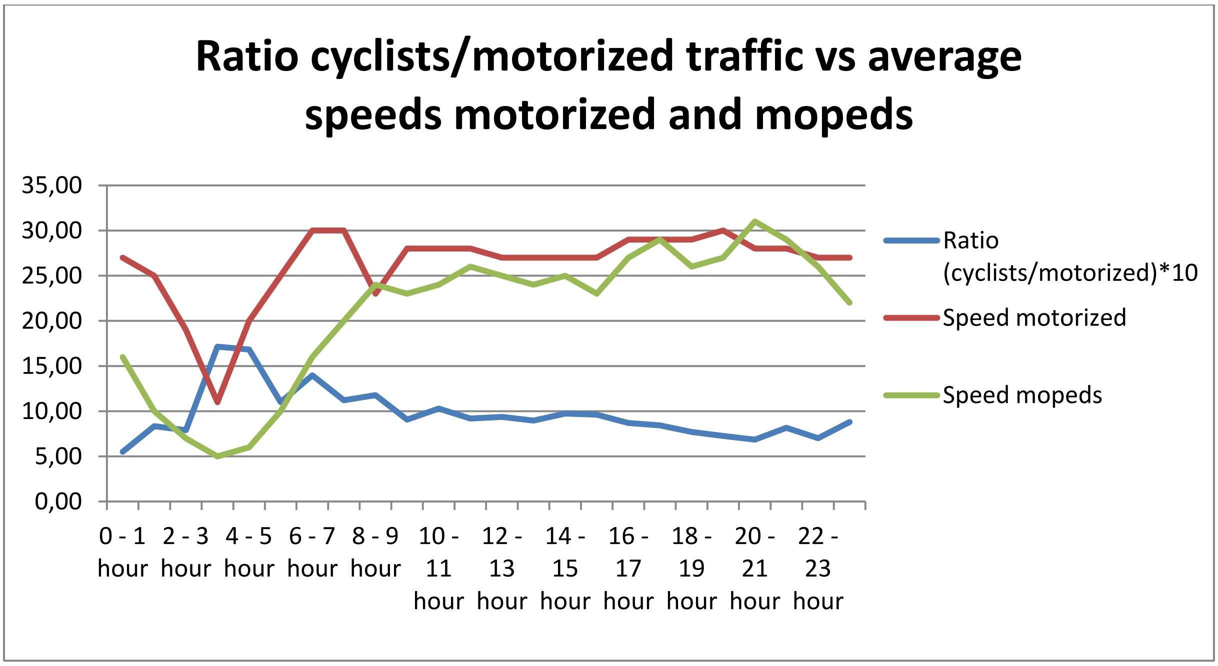

FIGURE 85: AVERAGE SPEEDS OF MOTORIZED VEHICLES AND MOPEDS VERSUS THE RATIO CYCLISTS/MOTORIZED VEHICLES

The relation between the high number of cyclists and the dip in the average speed of motorized vehicles has been shown in Figure 86. The left axe represents both the number of bicycles as the speed of motorized vehicles at the bicycle street. It is clear that there is a dip in the average speed of motorized vehicles when the intensity of bicycles is high. On the rest of the day, the average speed is not affected by the variation in the number of cyclists over the day.

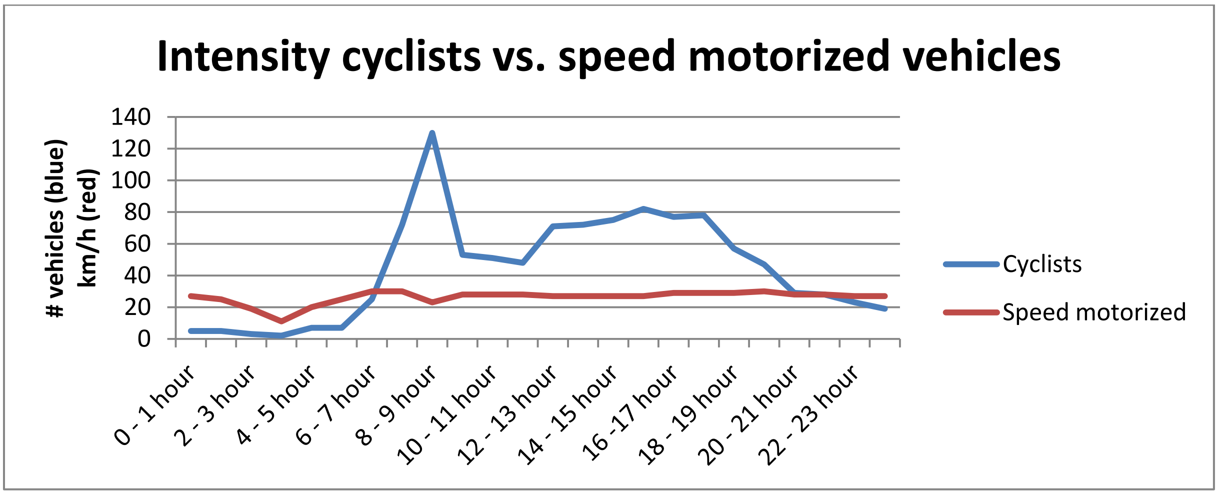

FIGURE 86: INTENSITY OF BICYCLES VERSUS THE SPEED OF MOTORIZED VEHICLES

The scatter plot in Figure 87 shows also that there is no relation between the ratio cyclists/motorized vehicles and the average speed of motorized vehicles on the bicycle street. Data between midnight and 6 a.m. has not been taken into account, since there are too less values to create a representative mean speed and ratio.

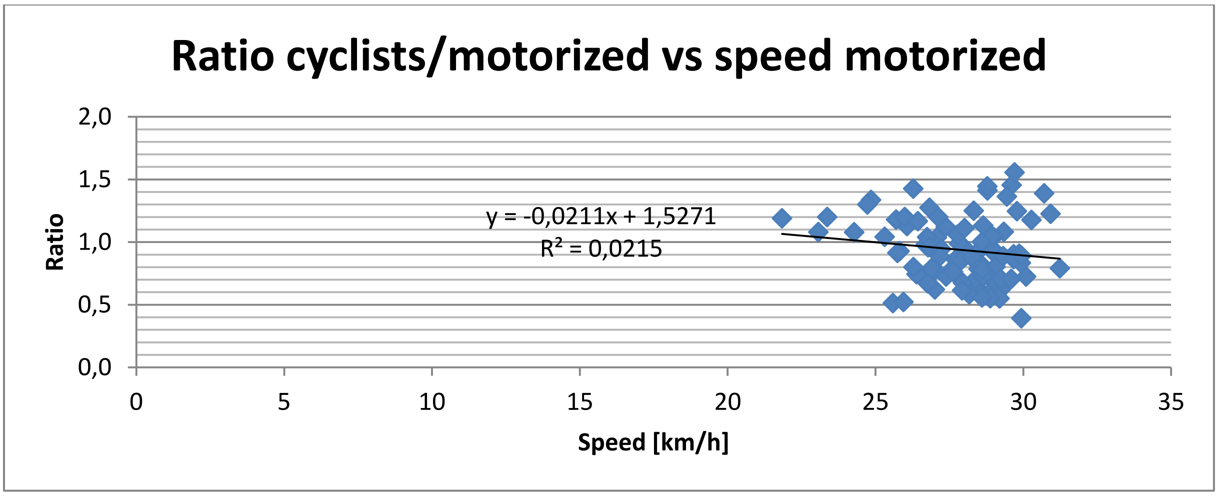

FIGURE 87: RATIO CYCLISTS/MOTORIZED VEHICLES VERSUS THE AVERAGE SPEED OF MOTORIZED VEHICLES

In addition to the conclusion that a large volume of cyclists affects the average speed of motorized vehicles, also the average speed versus the number of cyclists has been plotted in a scatter plot. This plot is given in Figure 88.

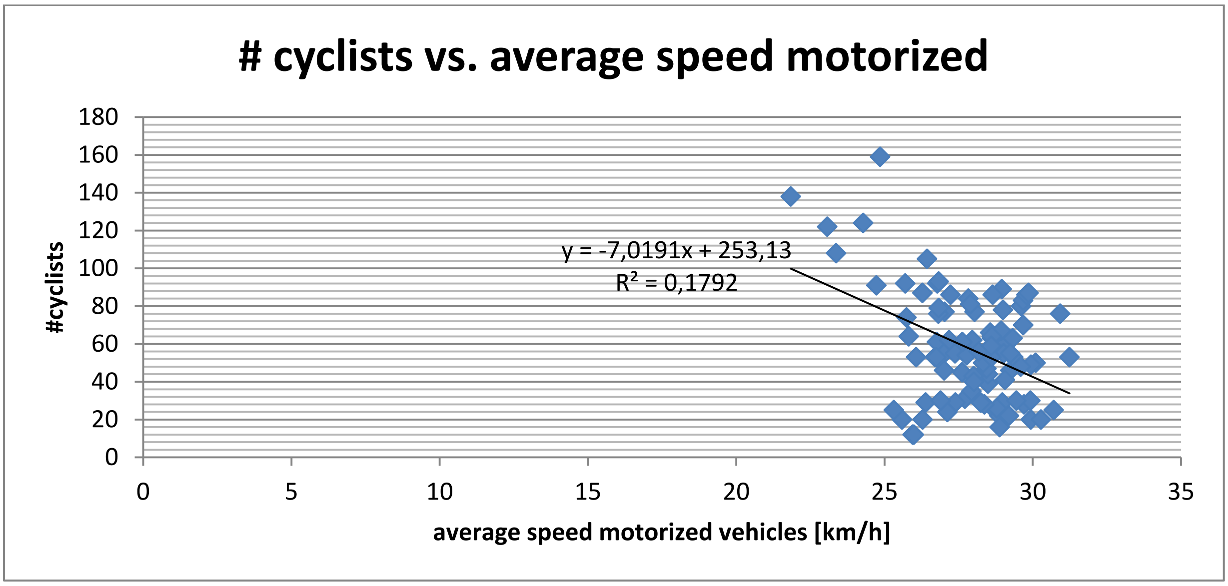

FIGURE 88: NUMBER OF CYCLISTS VERSUS THE AVERAGE SPEED OF MOTORIZED VEHICLES

In Figure 88 can be seen that there is a stronger relation between the absolute number of cyclists and the average speed of the motorized vehicles than between the ratio cyclists/motorized and the average speed of the motorized vehicles. This supports the statement that a large volume of cyclists enforces a low speed at the bicycle street.

Prinses Ireneweg, Houten

Observations

The traffic at the Prinses Ireneweg has been observed during the morning peak hour between 8.20 a.m. and 9.35 a.m. The traffic counts have shown that this is the busiest moment of the whole day. During this hour, many students passed on their way to the secondary school at the end of the bicycle street.

Information:
Wednesday 24th April 2013
Location: Prinses Ireneweg, intersection with Kamillehof
Time: 8.20 a.m. till 9.35 a.m.

The two-lane bicycle street design enforces cars more to stay behind the cyclists than the single-lane bicycle street design

The Prinses Ireneweg is a single-lane bicycle street.
During the observation period, there was a large flow of cyclists in the direction of the school at the northern end of the bicycle street. The main flow of cars was in the same direction. Those cars stayed behind the cyclists at the bicycle street, since there was also traffic coming in the opposite direction. There were no opportunities to pass during the opening times of the school.
In the second half of the observation period, the flow of cyclists and cars was much smaller. Cars had to deal with one or two cyclists in front of them. But even when the traffic volume was smaller, many cars stayed behind the cyclists. Only a few cars did pass the cyclists at the bicycle street.

Cars do not give priority to the traffic on the bicycle street when crossing or entering the bicycle street

In this study, the intersections between the Prinses Ireneweg and the Kamillehof, Prins Willem Alexanderweg and Koningin Emmalaan have been observed. During the observations, several vehicles, mainly cars, have entered or crossed the bicycle street via those intersections. All those vehicles gave priority to the traffic at the bicycle street. No conflicts have been observed between traffic entering or crossing the bicycle street and traffic at the bicycle street.

Cars parked along the bicycle street are not a large problem for the traffic safety at the bicycle street

Along the whole Prinses Ireneweg, parking spots are present. Some parking spots are perpendicular to the bicycle street, other parking spots are parallel to the street. During the observations, a few cars arrived or departed from a parking spot. In all those cases, there was no other traffic present at the bicycle street. So no conflicts between parked cars and traffic at the bicycle street has been observed.
What has been observed is a taxi van, stopping at the bicycle street to pick up someone. The van blocked one half of the bicycle street and traffic coming from behind had to pass the van via the other half of the street. At this moment, the traffic flows were low, so no conflicts could be observed.

Cars drive at the same speed as cyclists on bicycle streets

Most cars stay behind the cyclists at the bicycle street, even when the traffic volume is low and there are possibilities to pass. So the cars drive at the same speed as the cyclists in front of them. At the moment the traffic volume is low, some cars pass the cyclists. The passing manoeuvre takes often a long time, which indicates that the speed differences are small.

Even when there are no cyclists at the bicycle street, cars drive at a low speed at the bicycle street. This low speed will partly be enforced by the speed bumps at every intersection. However, the speed of cars is lower when cyclists are present at the bicycle street than when there are no cyclists present.

Data

The road tube counters have been placed at the stretch between the Prins Willem Alexanderweg and the Koningin Emmaweg. This stretch is the nearest stretch to the Rondweg, the main ring road around Houten. This stretch is therefore not only used by many cyclists, but is also part of the route of many cars.

<u>Information</u>
Collection period: 25th March till 3rd April 2013
Used period: 26th March till 1st April 2013
Average weather: cold (max. 5° C), dry
Location: Prinses Ireneweg between Prins Willem Alexanderweg and Koningin Emmaweg
Direction A: Prins Willem Alexanderweg
Direction B: Koningin Emmaweg

Cars drive at the same speed as cyclists on bicycle streets

The speeds that have been measured at the Prinses Ireneweg are presented in a box plot in Figure 89. The speeds of cyclists are concentrated around 17 km/h, the speeds of light motorized vehicles around 30 km/h and the speeds of medium and heavy motorized vehicles in between. The mean speed of mopeds is rather high and the variance is large.

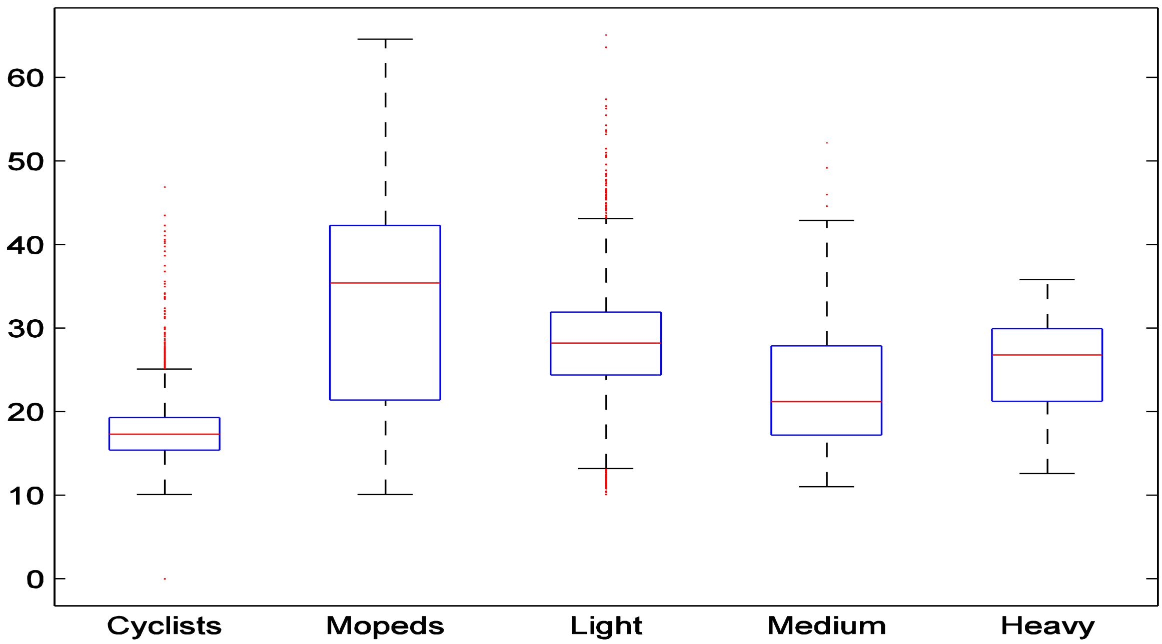

FIGURE 89: SPEEDS DRIVEN ON THE PRINSES IRENEWEG, PER CATEGORY

Figure 90 gives a more detailed look on the speed distributions of the different vehicle categories by dividing the data in different speed classes. In Figure 90 can be seen that the speeds of cyclists are concentrated between 15 and 25 km/h and most motorized vehicles drive at a speed between 25 and 35 km/h. This speed behaviour is comparable with the bicycle street in Haarlem. Also the speed behaviour of mopeds is similar: two peaks, one around 20 km/h and one around 40 km/h.

Although the speeds of cyclists and motorized vehicles are not the same, the speed choice of the motorized vehicles is considered as safe, since many vehicles drive slower than 30 km/h.

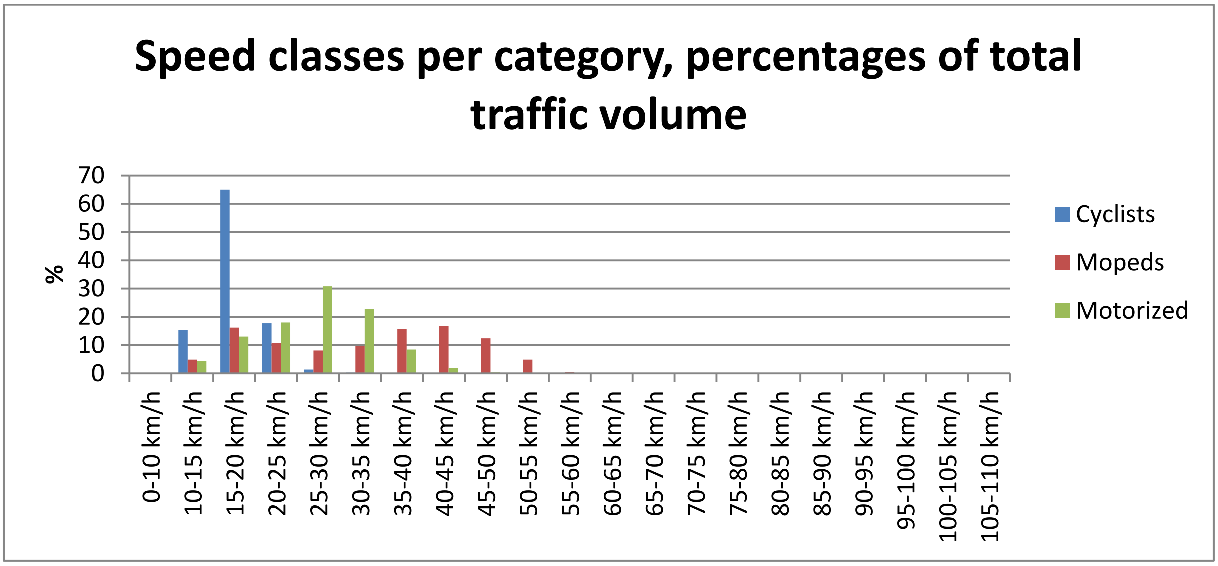

FIGURE 90: SPEED CLASSES PER CATEGORY ON THE PRINSES IRENEWEG

There should be more cyclists than cars on the bicycle street to enforce a low speed

The volume of cyclists at the Prinses Ireneweg is larger than the volume of motorized vehicles. Further, the speed of motorized vehicles is low, so the statement seems to be accepted. However, the speed behaviour has been analysed to find out whether the low speed is caused by the presence of cyclists or other factors.

Therefore, the average speeds of motorized vehicles and mopeds have been plotted together with the ratio cyclists/motorized vehicles. This plot is given in Figure 91.

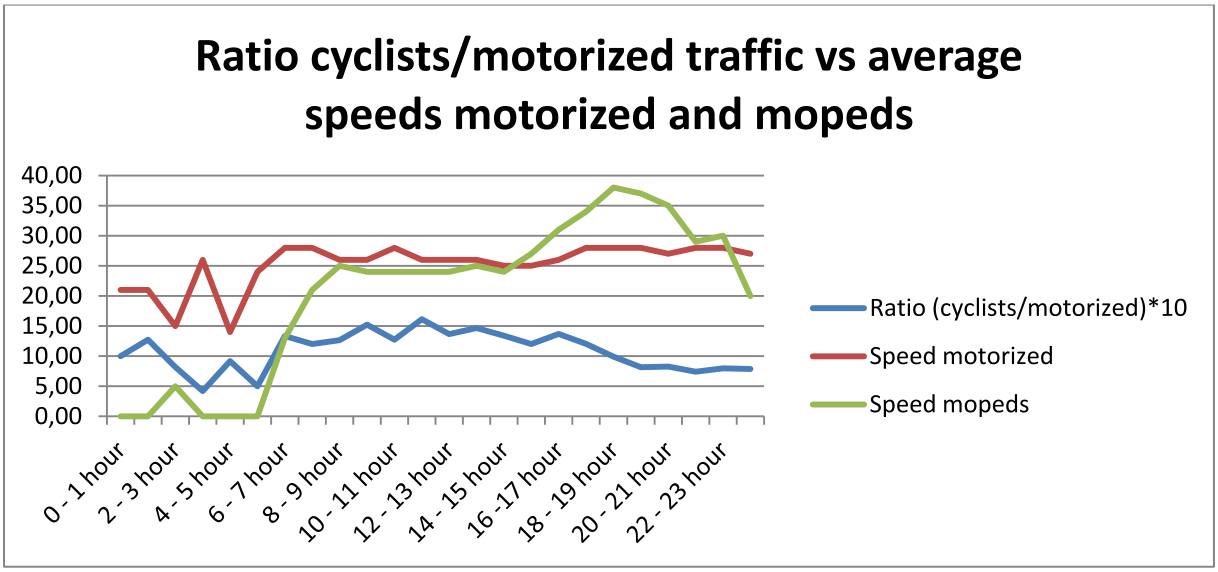

FIGURE 91: RATIO CYCLISTS/MOTORIZED VEHICLES VERSUS THE AVERAGE SPEEDS OF MOTORIZED VEHICLES AND MOPEDS

Figure 91 does not show a relation between the ratio and the average speed of motorized vehicles. Interesting is the high mean speed of mopeds in the evening. The values of the average speeds and ratio between midnight and 6 a.m. are not representative due to the low intensities at the bicycle street between those times.

Figure 92 shows that the average speed of motorized vehicles is almost constant over the day and is not affected by the number of cyclists at the bicycle street.

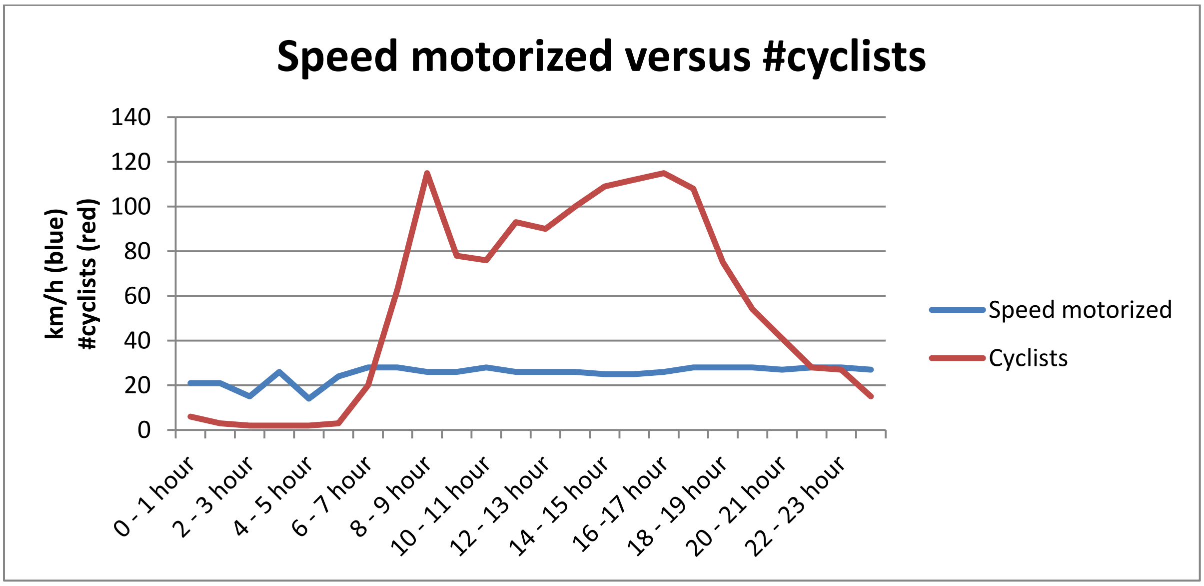

FIGURE 92: AVERAGE SPEED OF MOTORIZED VEHICLES VERSUS THE NUMBER OF CYCLISTS

To be sure that there is no relation between the number of cyclists and the average speed of motorized vehicles, the ratio cyclists/motorized vehicles versus the average speed of motorized vehicles has been plot in a scatter plot. This scatter plot is given in Figure 93. The trend line and R^2-value show that there is no relation between the ratio and the average motorized speed.

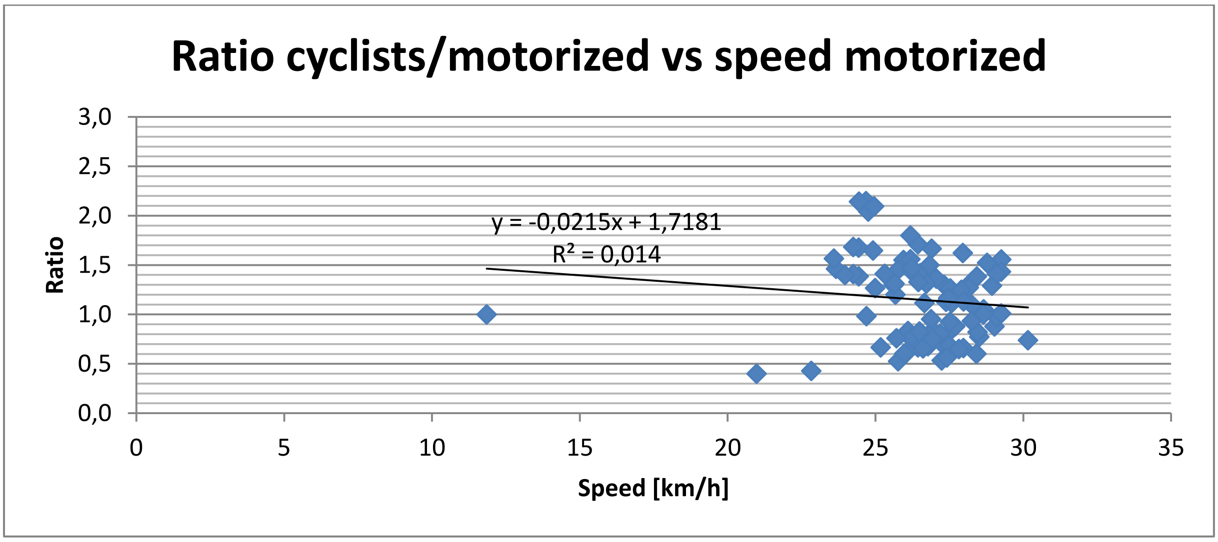

FIGURE 93: RATIO CYCLISTS/MOTORIZED SPEED VERSUS THE AVERAGE SPEED OF MOTORIZED VEHICLES

Asterstraat, Oss

Observations

The traffic at the Asterstraat in Oss has been observed during the morning peak hour, between 8 and 9 a.m. During this hour, many students have passed, cycling to their secondary school at both ends of the bicycle street.

Information:
Friday 19th April 2013
Location: Asterstraat, intersection with Seringenhof
Time: 7.50 a.m. till 9.00 a.m.

The two-lane bicycle street design enforces cars more to stay behind the cyclists than the single-lane bicycle street design

Since the rabat strip is rather small and there are a lot of cars parked directly along the rabat strip, almost all cyclists cycle at the asphalt carriageway in the middle of the street. Cars can only pass cyclists when there is no traffic in the opposite direction. Since there are many cyclists in both directions, cars stay behind the cyclists, or pass only after a while when there is no traffic in the opposite direction.
Large groups of cyclists, mostly students, are using the bicycle street in both directions. Those groups often use a large part or even the whole width of the bicycle street and cycle with three or four cyclists next to each other. Those groups make it impossible for cars to pass, but are also an obstacle for faster cyclists coming from behind, or cyclists in the opposite direction.

Cars do not give priority to the traffic on the bicycle street when crossing or entering the bicycle street

In this study, the intersection between the Asterstraat and the Seringenhof has been observed during one hour. During this period, a couple of cars has entered the Asterstraat from the Seringenhof. All those cars gave priority to the traffic at the bicycle street.

Cars parked along the bicycle street are not a large problem for the traffic safety at the bicycle street

On both sides of the bicycle street, parking spots have been realized. During the observation period, almost all parking spots were occupied. Only a few cars departed or arrived at a parking spot during the observations. Most cars departed or arrived when there was no other traffic at the bicycle street, so no conflicts could be observed. Two parked cars caused conflicts at the bicycle street.
The first parked car had the doors opened for several minutes. The doors reached till the asphalt strip of the bicycle street and several cyclists had to manoeuvre around the opened doors. The second parked car left the parking spot just before a group of cyclists. Those cyclists had to brake to avoid a crash.

Cars drive at the same speed as cyclists on bicycle streets

During peak hours, there are large flows of cyclists in both directions at the bicycle street. Only a few cars are using the bicycle street and most cars have its origin or destination directly along the bicycle street. Cyclists have a dominant position at this bicycle street. Cars have to stay behind the cyclists since there are no possibilities to pass the cyclists in front of the car. Cars wait until there is absolutely no traffic in the opposite direction before they pass the cyclists in front of the car. If a car passes one or more cyclists, the speed of the car is low. When there are no cyclists at the bicycle street, the speed of cars is a bit higher.

Data

The road tube counters have been placed at the middle stretch of the Asterstraat, between the Seringenhof and the Anjeliersstraat. This location has been chosen based on the available evaluation studies of the bicycle street in Oss. Earlier traffic counts have taken place at the exact same location, which makes it possible to compare the new traffic counts with the older traffic counts.

<u>Information</u>
Collection period: 25th March till 3rd April 2013
Used period: 26th March till 1st April 2013
Average weather: cold (max. 5° C), dry
Location: Asterstraat between Seringenhof and Anjeliersstraat
Direction A: Anjeliersstraat
Direction B: Seringenhof

Cars drive at the same speed as cyclists on bicycle streets

An overview of the speeds per vehicle category is provided by Figure 94. In this box plot can be seen that the speeds of cyclists are concentrated just below 20 km/h and that the variance is small. The mean speed of motorized vehicles lies around 35 km/h and the variance is large. The distribution of the speeds of medium and heavy good vehicles are unusual, caused by the small volume of medium and heavy good vehicles that have passed the road tube counters. The mean speed of mopeds is rather low, compared with the speed behaviour of mopeds on other bicycle streets. However, the variance is very large, indicating that also many mopeds are driving much faster than the mean speed of about 25 km/h.

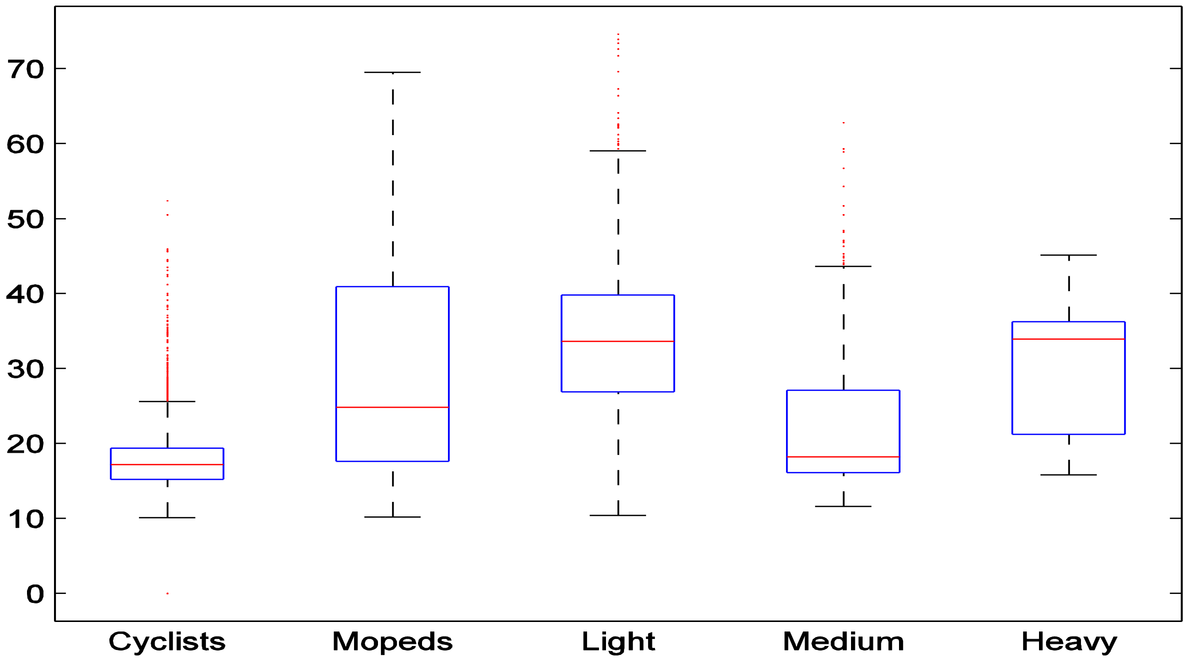

FIGURE 94: SPEEDS PER VEHICLE CATEGORY DRIVEN ON THE ASTERSTRAAT IN OSS

A more detailed look into the speed distributions of the different vehicle categories is provided by Figure 95. Figure 95 shows the speeds per vehicle category split up into different speed classes. From this plot can be seen that 50 percent of the mopeds drives at a speed of less than 30 km/h, so the other 50 percent drives faster. The speeds of cars show two peaks, one around 15-20 km/h, the same speed as most cyclists, and one around 30-35 km/h. This second peak is a bit higher than has been seen on the other bicycle streets. Speeds above 30-35 km/h are not considered as safe speeds, since the chance of surviving a crash with a motorized vehicle as a pedestrian or cyclist decreases rapidly.

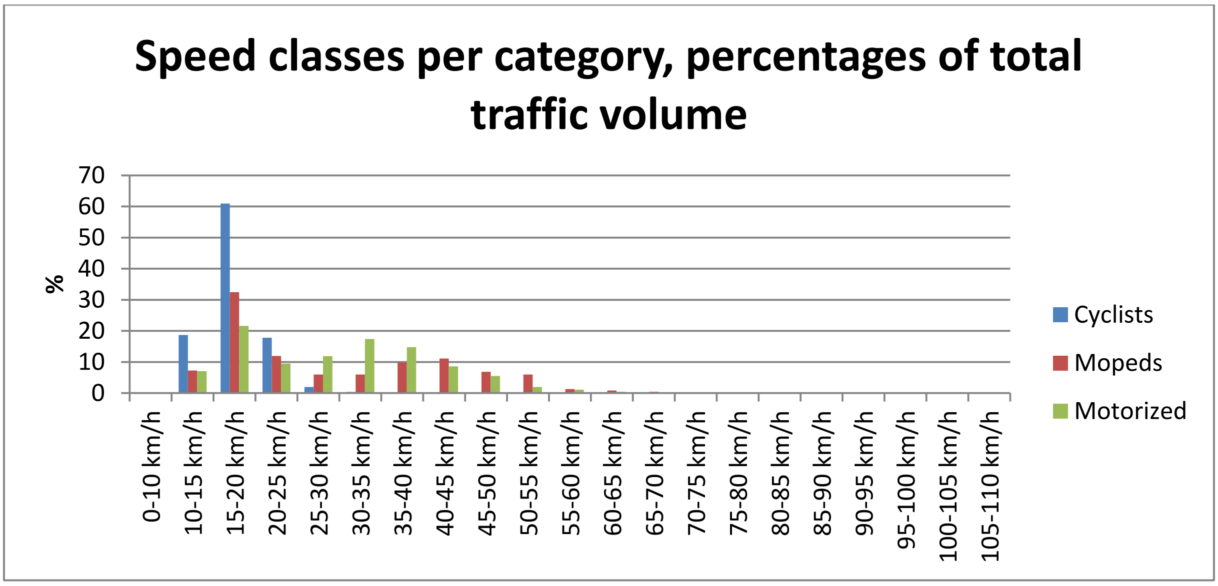

FIGURE 95: SPEED CLASSES ON THE ASTERSTRAAT PER VEHICLE CATEGORY

From Figure 95 can be concluded that a large part of the mopeds and motorized vehicles drives at the same speed as cyclists on the bicycle street. However, another large part drives at a higher speed, a speed that is not considered as a safe speed.

There should be more cyclists than cars on the bicycle street to enforce a low speed

This statement suggests that the speed of cars depends on the ratio cyclists/motorized vehicles. Therefore, the ratio cyclists/motorized vehicles has been plotted versus the average speeds of motorized vehicles and mopeds. This plot is given in Figure 96.

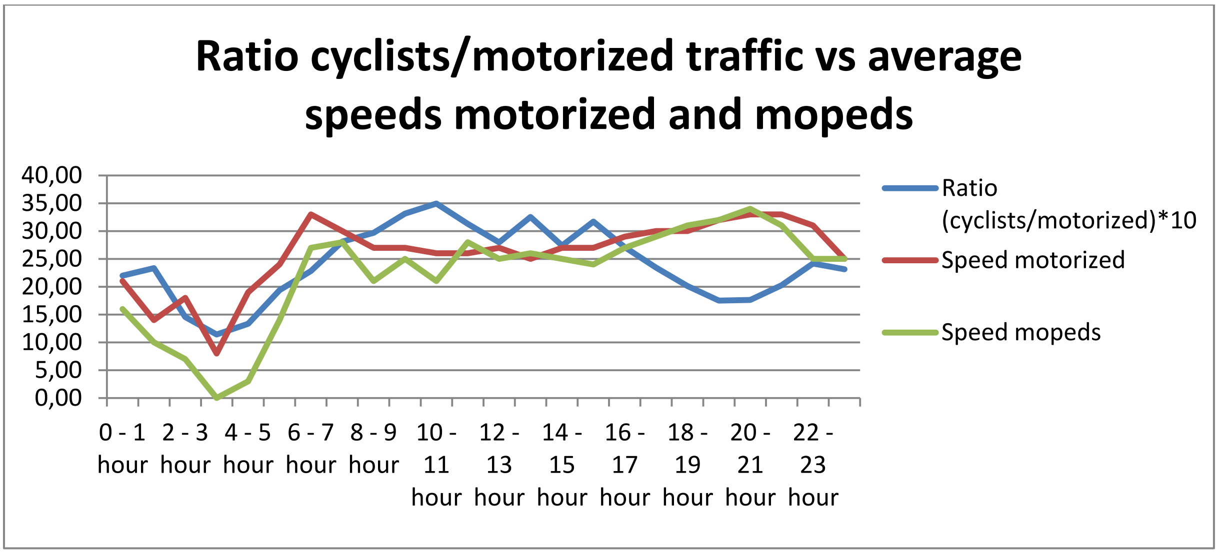

FIGURE 96: RATIO CYCLISTS/MOTORIZED VEHICLES VERSUS THE AVERAGE SPEEDS OF MOTORIZED VEHICLES AND MOPEDS ON THE ASTERSTRAAT

The values of the ratio and the average speeds between midnight and 6 a.m. are not representative for the real situation at the bicycle street, since too less vehicle passed during these hours to give a representative value.

Between 6 and 8 a.m., the ratio increases while the average speed decreases. Over the day, the ratio varies but the average speed stays the same. In the evening, the ratio decreases and the average speed increases. So there are several indications for a relation between the ratio and the average speed. This relation has been further investigated by plotting the ratios and average speeds in a scatter plot. Data between midnight and 6 a.m. has been left out of the scatter plot in Figure 97.

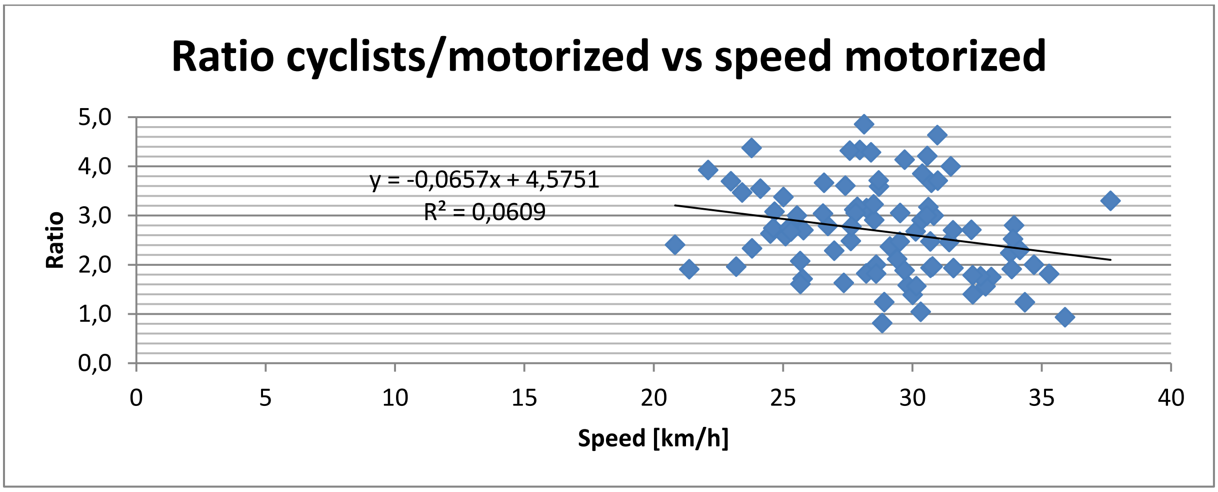

FIGURE 97: RATIO CYCLISTS/MOTORIZED VEHICLES VERSUS THE AVERAGE SPEED OF MOTORIZED VEHICLES

The scatter plot does not show a relation between the ratio and the average speed, since the R^2 is too small. Therefore, also the relation between the average speed of motorized vehicles and the average intensity of cyclists has been investigated. In Figure 98, the number of cyclists has been plotted together with the average speed of motorized vehicles. Also this plot does not directly show a relation between the number of cyclists and the average speed of motorized vehicles, besides the decreasing average speed in the morning and the increasing speed in the evening.

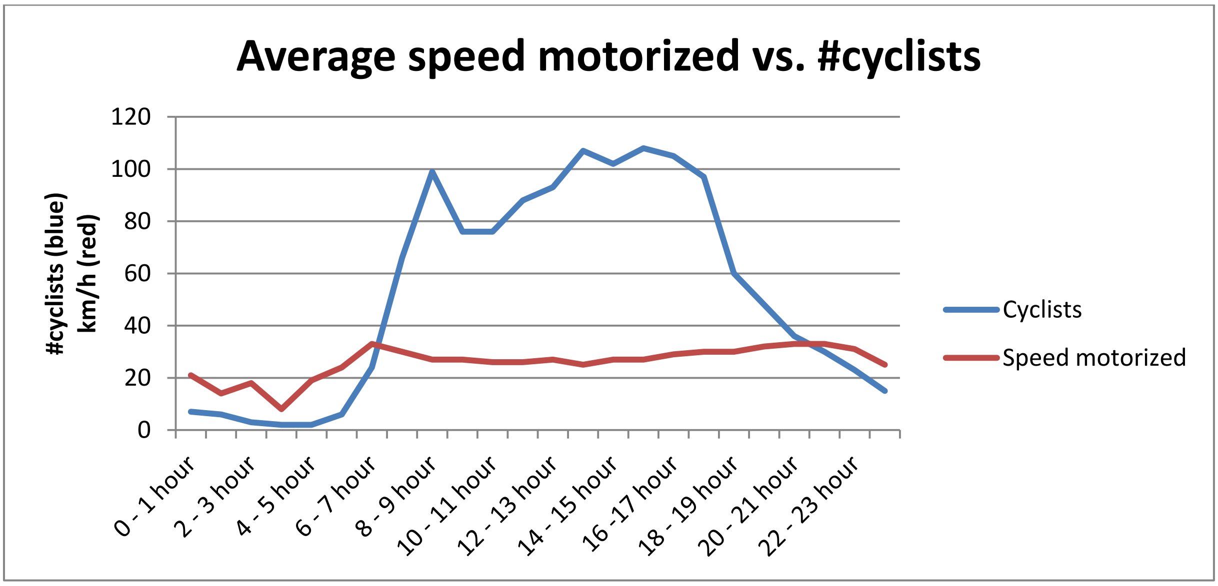

FIGURE 98: AVERAGE SPEED OF MOTORIZED VEHICLES TOGETHER WITH THE NUMBER OF CYCLISTS

In Figure 99, the average speed of motorized vehicles has been plotted in a scatter plot versus the number of cyclists. The R^2 of the trend line is rather high, indicating a correlation. However, the spread of data points around the trend line is still quite large. So there is an indication for a relation between the number of cyclists and the average speed of motorized vehicles, but this relation is not strong. The speed choice of motorized vehicles will probably depend on more factors than only the presence of cyclists on the bicycle street.

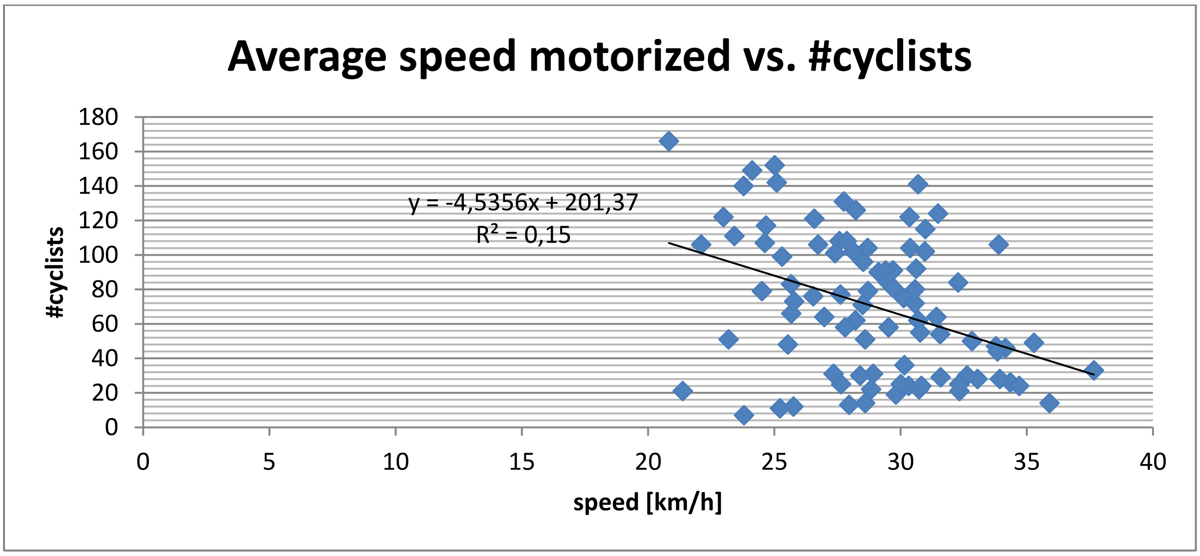

FIGURE 99: SCATTER PLOT WITH THE AVERAGE SPEED OF MOTORIZED VEHICLES AND THE NUMBER OF CYCLISTS AT THE BICYCLE STREET

Vondelkade, Zwolle

Observations

Traffic at the Vondelkade in Zwolle has been observed during the morning peak hour, since this is the busiest hour at the bicycle street. During the observations, many parents with their children passed on their way to the elementary school close to the bicycle street.

Information:
23th April 2013
Location: Vondelkade, intersection Tesselschadestraat
Time: 8.15 a.m. till 9.30 a.m.

The two-lane bicycle street design enforces cars more to stay behind the cyclists than the single-lane bicycle street design

The Vondelkade in Zwolle is a single-lane bicycle street.
At the Vondelkade, large flows of cyclists have been observed in both directions. Only a few cars were using the bicycle street. Due to the large traffic flows in both directions, cars have not that many opportunities to pass the cyclists in front of the car. The cars at the bicycle street stay therefore behind the cyclists. Only when there is no other traffic in the opposite direction, cars will pass the cyclists and only at a low speed.
Due to the large flows of cyclists in both directions, cyclists do only cycle at their own half of the street. Even large groups of students pass by with a maximum of two cyclists next to each other.

Cars do not give priority to the traffic on the bicycle street when crossing or entering the bicycle street

In this study, the intersections between the Vondelkade and the Roemer Visscherstraat and Jacob Catsstraat have been observed. Traffic coming from both streets to the Vondelkade has to give priority to traffic at the Vondelkade. During the observation period of one hour and fifteen minutes, each vehicle coming from one of those streets gave priority to the traffic at the bicycle street.

Cars parked along the bicycle street are not a large problem for the traffic safety at the bicycle street

Along the Vondelkade, parking spots have been realized on one side of the street. During the observation period, several cars parked or departed from a parking spots. However, in most cases this happened when there was no other traffic present at the bicycle street. So no conflicts between parking or departing cars and other traffic at the bicycle street have been observed.
What has been observed is a delivery van stopping at the bicycle street to deliver a package. This van blocked the bicycle street in one direction. Cyclists passed the van on both sides, while cars in the opposite direction pass the van.

Cars drive at the same speed as cyclists on bicycle streets

In the first place, there are not that many cars at the bicycle street, especially compared with the number of cyclists. The cars that are present at the bicycle street have their origin or destination directly along the bicycle street or the surrounding streets. The cars that are present at the bicycle street stay mostly behind the cyclists since they only have to follow the cyclists for a short distance. There are even no possibilities to pass the cyclists during the peak hours, since the traffic flow in both directions is large. After peak hours, when the traffic flows are significantly smaller, cars pass the cyclists in front of the car, but the speed is still low. Even when there are no cyclists present at the bicycle street, cars drive at a low speed at the bicycle street.

Data

The road tube counters have been placed on the Vondelkade between the Vechtstraat and the Jacob Catsstraat. This is the stretch closed to the city centre and therefore the most busiest part of the bicycle street.

<u>Information</u>
Collection period: 22nd March till 9th April 2013
Used period: 23rd March till 29th March 2013
Average weather: cold (max. 5° C), dry
Location: Vondelkade
Direction A: Jacob Catsstraat
Direction B: Vechtstraat

Cars drive at the same speed as cyclists on bicycle streets

The speeds that are driven at the bicycle street are presented in a box plot in Figure 100. This box plot shows that the speeds of cyclists are concentrated just below 20 km/h. Speeds of light motorized vehicles are concentrated around 30 km/h, but the variance is quite large. Medium and heavy motorized vehicles have lower speeds, but not enough heavy vehicles have passed to give a representative value for the mean speed and the variance. The mean speed of mopeds is quite low, especially compared with other bicycle streets, but the variance is large.

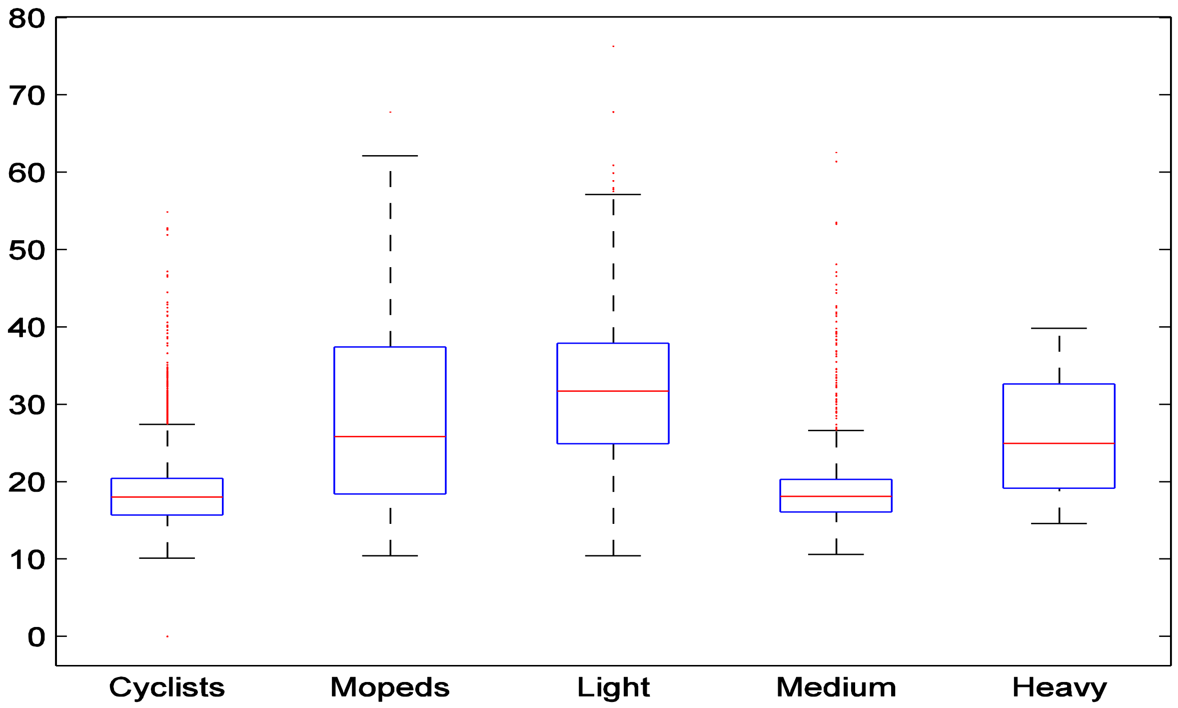

FIGURE 100: SPEEDS PER VEHICLE CATEGORY ON THE VONDELKADE

A more detailed look is provided by a division in speed classes per vehicle category. This division is plotted in Figure 101.

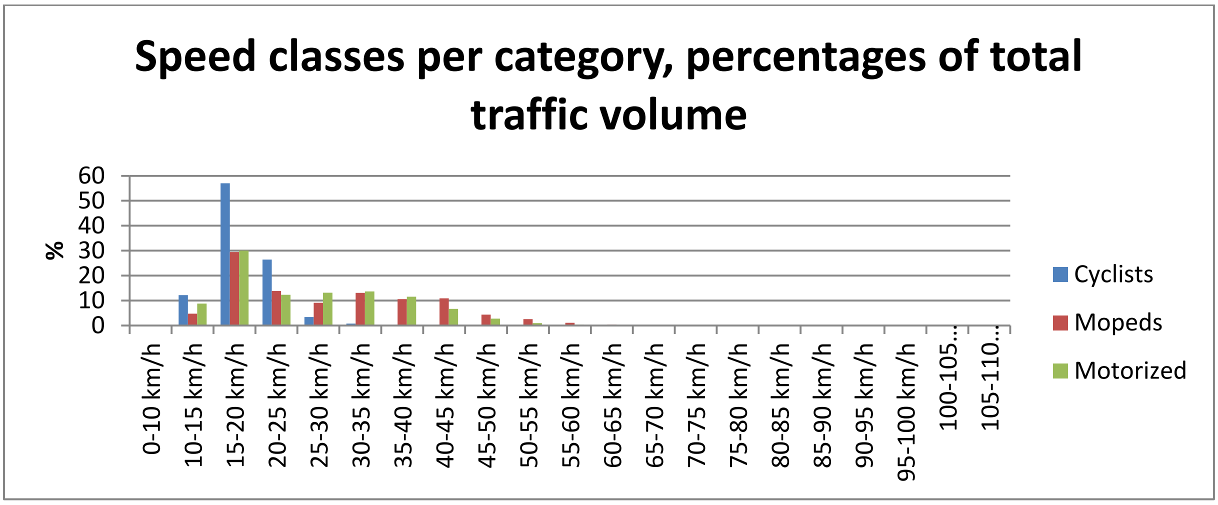

FIGURE 101: SPEED CLASSES PER VEHICLE CATEGORY ON THE VONDELKADE

Figure 101 shows a concentration of speeds of cyclists, mopeds and motorized vehicles between 15 and 25 km/h. A large part of the mopeds and motorized vehicles drives at the same speed as cyclists at the bicycle street. There could be concluded that most of the motorized vehicles drive at a speed lower than 35 km/h. The speed behaviour of motorized vehicles on the bicycle street is safe.

There should be more cyclists than cars on the bicycle street to enforce a low speed

To investigate whether the low speeds at the bicycle street are caused by the large volume of cyclists, the ratio cyclists/motorized vehicles has been plotted together with the average speed of motorized vehicles and mopeds. This plot is given in Figure 102.

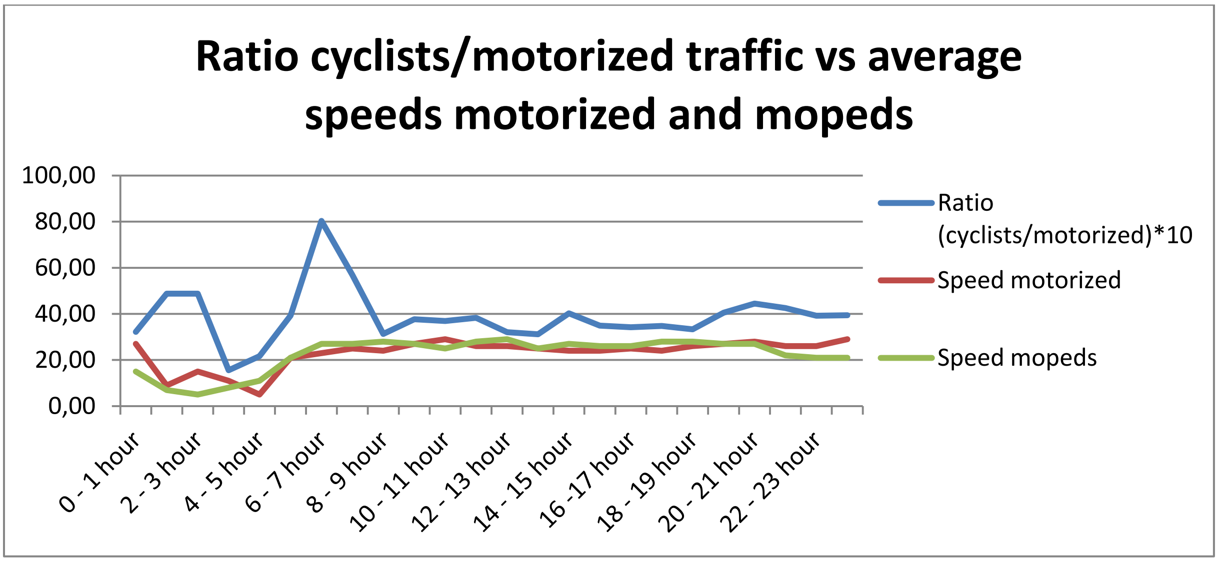

FIGURE 102: RATIO CYCLISTS/MOTORIZED VEHICLES VERSUS THE AVERAGE SPEEDS OF MOTORIZED VEHICLES AND MOPEDS

In Figure 102, not a real relation between the ratio and the average speed could be found. Therefore a scatter plot has been made, containing the ratio and the average speeds. The speeds between midnight and 6 a.m. are not included in this scatter plot since the intensities are too low in this period to give a representative value of the average speed and the ratio. The scatter plot is given in Figure 103.

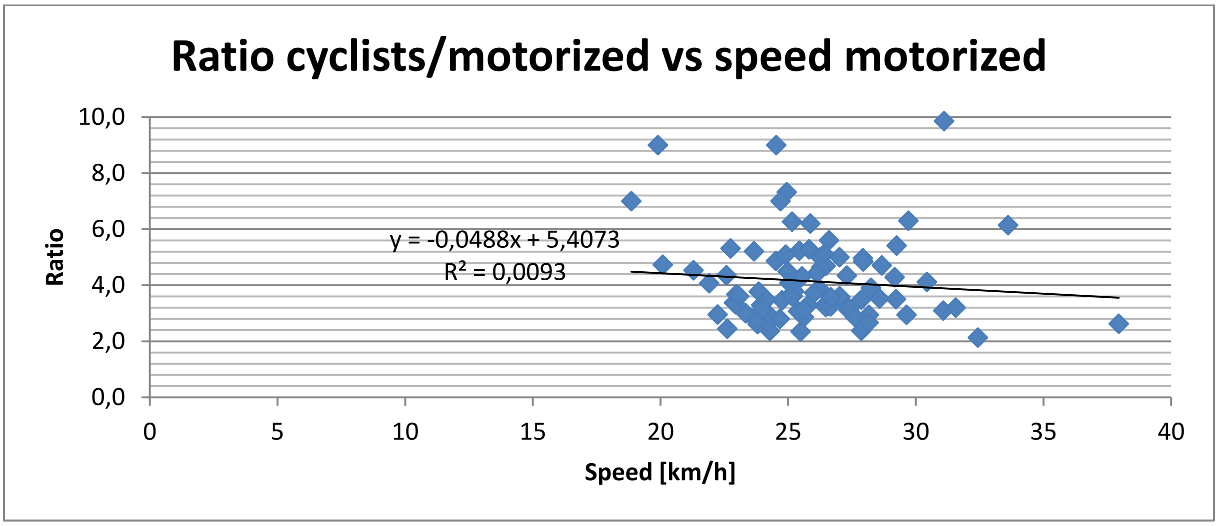

FIGURE 103: SCATTER PLOT WITH THE RATIO CYCLISTS/MOTORIZED VEHICLES AND THE AVERAGE SPEED OF MOTORIZED VEHICLES

Figure 103 does not show any correlation between the average speed and the ratio. The small value for R^2 indicates also that there is no correlation between the ratio and the speed.

Figure 104 shows that there is a stronger correlation between the absolute number of cyclists and the average speed of motorized vehicles. The higher value of R^2 indicates a stronger relation between the number of cyclists and the average speed than the relation between the ratio cyclists/motorized vehicles and the average speed.

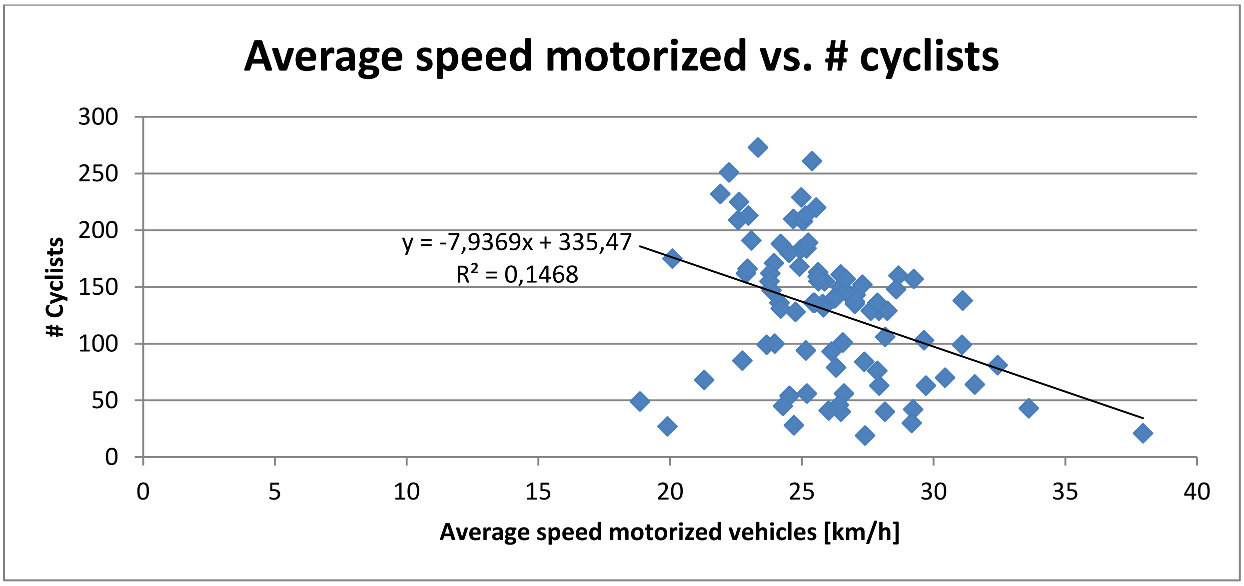

FIGURE 104: AVERAGE SPEED OF MOTORIZED VEHICLES VERSUS THE AVERAGE INTENSITY OF CYCLISTS

APPENDIX C: INTERVIEWS WITH ROAD AUTHORITIES

A questionnaire was sent to the road authorities of the eight bicycle streets. Five road authorities have answered the questionnaires. The answers are used as background information and for validation of the found results of for example the function analysis. Unfortunately, the questions and answers are in Dutch, since Dutch road authorities have answered the interviews.

Vragenlijst fietsstraat Frieseweg

Waarom is besloten om de Frieseweg in te richten als fietsstraat?

Handtekeningen actie van bewoners Frieseweg. Zij vonden intensiteiten te hoog, percentage vrachtverkeer was hoog, rijsnelheid lag hoog voor 30 km/u zone en bewoners klaagden over trillingshinder door klinkerbestrating. Tegelijk hoge intensiteiten fietsverkeer en onduidelijke voorrangssituaties.

Welke functies heeft de fietsstraat? Denk aan woonstraat, hoofdfietsroute, wijkontsluiting, OV-route, winkelgebied.

De Frieseweg is onderdeel van de hoofdfietsroute tussen Alkmaar-Noord en het centrum van Alkmaar. Het is verder onderdeel van een OV-route en verwerkt 8 bussen per uur. Er zijn een aantal kleine bedrijfjes langs de Frieseweg gevestigd die ook een beetje vrachtverkeer genereren. Verder ontsluit de Frieseweg een aantal achterliggende straten. Verder vormt de Frieseweg de kortste verbinding tussen het centrum van Alkmaar en Alkmaar-Noord en is daarmee ook aantrekkelijk voor gemotoriseerd verkeer.

Leidt de genoemde combinatie van functies tot knelpunten en zo ja, welke?

Ja, bussen hebben neiging om door te jakkeren op fietsstraat. Dit conflicteert door het verschil in massa en snelheid met de hoofdfietsroutes. Bussen veroorzaken gevoel van onveiligheid.

Wat is uw beeld als wegbeheerder over het functioneren van de fietsstraat? Positief/Negatief, waarom?

Positief, uitvoeren in asfalt verminderd onderhoud aan weg vergeleken met klinkerbestrating. Verder positief over de gedaalde auto-intensiteiten en vooral de gedaalde intensiteiten van zwaar verkeer. Ook de gemiddelde snelheid en V85 is gedaald.

Wat is het beeld over het functioneren onder de gebruikers en aanwonenden? Zijn er klachten bekend? Is een evaluatieonderzoek beschikbaar?

Fietsersbond is erg te spreken over de inrichting als fietsstraat. Aanwonenden klagen nog over de hoge rijsnelheden van het gemotoriseerd verkeer, zeker 's avonds als er weinig fietsers zijn.

Zijn er intensiteiten bekend van langzaam en snelverkeer? Wat is de samenstelling van het snelverkeer? Is er een verdeling over de dag bekend?

Voor de herinrichting zaten er op het zuidelijk deel van de Frieseweg ongeveer 5000 mvt/etmaal en eenzelfde aantal fietsers. Het percentage zwaar verkeer was 8%. Na de herinrichting is het aantal mvt/etmaal sterk gedaald, exacte cijfers ontbreken maar aan de hand van een snelheidsmonitor wordt het aantal op 1500 tot 2000 mvt/etmaal geschat. De middagspits de stad uit is het drukst.

Zijn er snelheidsmetingen uitgevoerd (evt. door de politie) na de realisatie van de fietsstraat? Zijn de resultaten daarvan beschikbaar?

Er hebben op de fietsstraat snelheidsmonitors gehangen na de realisatie van de fietsstraat. Deze geven een V85-waarde aan van 40 km/u op de fietsstraat, waar 30 km/u is toegestaan.

Is het weggedrag op de fietsstraat zoals van te voren bedacht ten aanzien van:

a) **Gemotoriseerd verkeer?**
Ja, gemotoriseerd verkeer blijft achter de fietsers en kiest duidelijk een moment om in te halen. Verder past het gemotoriseerd verkeer de snelheid aan aan de fietsers als hoofdgebruiker van de fietsstraat.
b) **Langzaam verkeer?**
Langzaam verkeer profiteert duidelijk van de positie als hoofdgebruiker. Duidelijk zichtbaar is dat een groot aantal fietsers een positie midden op de rijloper verkiest boven een positie aan de zijkant. Het merendeel van de fietsers maakt ook niet direct plaats voor gemotoriseerd verkeer, er wordt meer gecommuniceerd tussen verschillende gebruikersgroepen.
c) **Parkeren?**
De Frieseweg kent een hoge parkeerdruk door de situering vlakbij de binnenstad en de jaren '30 huizen zonder parkeergelegenheid langs de Frieseweg. In de parkeervraag wordt voorzien door parkeerplaatsen langs de ventwegen van de Frieseweg en parkeerplaatsen aan de Frieseweg zelf. Op de Frieseweg zelf geldt een parkeerverbod. Af en toe worden auto's met twee wielen op het trottoir geparkeerd, meestal kort parkeren door bewoners zelf. Dit geeft weinig problemen.

Hebben er sinds de opening ongevallen plaatsgevonden op de fietsstraat? Zo ja, wat voor soort ongevallen (eenzijdig, fiets-fiets, fiets-bromfiets, fiets-auto; frontaal, flank) en op welke locatie?

Nee, voor zover bekend niet.

Waarom en hoe is gekozen voor een ontwerp met een middenberm? (Aan de hand van een extern advies, een voorbeeld elders, eigen ontwerp?)

De Dorpsstraat in Castricum heeft als voorbeeld gediend. De Grontmij is gevraagd om het ontwerp verder uit te werken, zij hebben een profiel met fietsers in het midden en met middenberm uitgewerkt. Het ontwerp met de middenberm had daarna zowel de voorkeur van de bewoners als van de gemeente.

Welke richtlijnen en/of publicaties zijn gebruikt om de vormgeving te bepalen?

Fietsberaad publicatie nr. 6 en de ontwerpen van de fietsstraat in Castricum zijn gebruikt om de vormgeving en de maten van het profiel te bepalen.

Heeft u een ontwerptekening van de fietsstraat voor mij beschikbaar zodat ik daar de maatvoering uit kan afleiden?

Ja, bijgevoegd.

Zijn na de opening nog aanpassingen verricht aan de fietsstraat om deze beter te laten functioneren? Zo ja, welke en waarom?

Na de opening is de middengeleider vervangen, deze was oorspronkelijk van betonnen elementen gemaakt en is later vervangen door asfalt met klinkerstreetprint. Dit is gedaan omdat de betonnen elementen losraakten en er daardoor gevaarlijke situaties ontstonden. Bij de asfaltering is niet dezelfde bolling van de middengeleider bereikt als bij de betonelementen het geval was, daardoor is deze nu makkelijker overrijdbaar. Verder zijn nog fietsstraatmarkeringen aangebracht aan de beginpunten en fietssymbolen op de rijloper na elk kruispunt.

Zijn er momenteel nog knelpunten op de fietsstraat bij u bekend? Waar bevinden zich deze?

Bij de aanleg van de fietsstraat is de rijbaan versmald van 6,60 meter naar 6 meter. De rijlopers zijn daardoor te smal geworden voor de bussen. Zij moeten daarom met twee wielen over de middengeleider rijden, hetgeen *trillingen- en geluidsoverlast veroorzaakt, maar ook de drempel om van de middengeleider gebruik te maken verlaagd.*

Hebt u verder nog ervaringen met de fietsstraat die u wilt delen?

Het gebruik van de fietsstraat door bussen is allerminst gelukkig, maar soms onvermijdelijk vanuit politiek oogpunt. Verder lijkt alleen al de inrichting als fietsstraat automobilisten af te schrikken en de auto-intensiteiten terug te dringen. De vervanging van de elementen door asfalt met streetprint lijkt geen effecten te hebben op de gereden snelheid, de V85 is hetzelfde gebleven.

Vragenlijst fietsstraat Ezelsveldlaan

Waarom is besloten om de Ezelsveldlaan in te richten als fietsstraat?

Belangrijke fietsverbinding, autoverbinding moet wel mogelijk zijn ivm doorstroming, maar heeft duidelijk minder primaat. Qua gebruik leent deze straat zich prima om als fietsstraat ingericht te worden; hoge fietsintensiteit, lage autointensiteit. Hiermee kan worden afgedwongen dat de automobilist zich als gast dient te gedragen. Inrichting kan je met die intensiteiten dan ook aanpassen op het gebruik; de fietsers kan meer in het midden van de rijloper fietsen.

Welke functies heeft de fietsstraat? Denk aan woonstraat, hoofdfietsroute, wijkontsluiting, OV-route, winkelgebied.

Winkelgebied, hoofdfietsroute

Leidt de genoemde combinatie van functies tot knelpunten en zo ja, welke?

nee

Wat is uw beeld als wegbeheerder over het functioneren van de fietsstraat? Positief/Negatief, waarom?

Positief. Maar gewenst gedrag automobilisten (nl. dat ze zich als gast gedragen, lage snelheid, achter fietsers blijven) is niet vanaf begin duidelijk geweest. In loop van de tijd wordt dit steeds beter. Ook omdat er inmiddels meerdere fietsstraten zijn gerealiseerd.

Rammelstrook in het midden had achteraf misschien wat verhoogd in een bolling aangelegd moeten worden. Hiermee had beter afgedwongen kunnen worden dat de automobilist achter fietsers blijven rijden.

Wat is het beeld over het functioneren onder de gebruikers en aanwonenden? Zijn er klachten bekend? Is een evaluatieonderzoek beschikbaar?

Nee, er is geen evaluatie onderzoek. Functioneert goed

Zijn er intensiteiten bekend van langzaam en snelverkeer? Wat is de samenstelling van het snelverkeer? Is er een verdeling over de dag bekend?

Meer dan 5.000 fietsers per dag versus maximaal enkele honderden motorvoertuigen. Telling moet hier antwoord op geven.

Zijn er snelheidsmetingen uitgevoerd (evt. door de politie) na de realisatie van de fietsstraat? Zijn de resultaten daarvan beschikbaar?

Nee

Is het weggedrag op de fietsstraat zoals van te voren bedacht ten aanzien van:

a) **Gemotoriseerd verkeer?**
   gaat steeds beter; was wennen. Meerdere fietsstraten zijn prettig om beter te kunnen communiceren wat verwacht wordt van weggebruikers
b) **Langzaam verkeer?**
   prima

c) Parkeren?

Is ongewenst; er wordt soms even geparkeerd op de rijbaan, terwijl dit niet de bedoeling is

Hebben er sinds de opening ongevallen plaatsgevonden op de fietsstraat? Zo ja, wat voor soort ongevallen (eenzijdig, fiets-fiets, fiets-bromfiets, fiets-auto; frontaal, flank) en op welke locatie?

nee

Waarom en hoe is gekozen voor een ontwerp met een middenberm? (Aan de hand van een extern advies, een voorbeeld elders, eigen ontwerp?)

Eigen ontwerp, conform ontwerp andere fietsstraten. Het profiel liet het toe om te kiezen voor een rammelstrook in het midden. Anders was er gekozen voor rabatstroken aan de zijkanten.

Welke richtlijnen en/of publicaties zijn gebruikt om de vormgeving te bepalen?

Crow (216)

Heeft u een ontwerptekening van de fietsstraat voor mij beschikbaar zodat ik daar de maatvoering uit kan afleiden?

Zo snel niet voorhanden. Op straat vrij makkelijk te bepalen

Zijn na de opening nog aanpassingen verricht aan de fietsstraat om deze beter te laten functioneren? Zo ja, welke en waarom?

nee

Zijn er momenteel nog knelpunten op de fietsstraat bij u bekend? Waar bevinden zich deze?

Nee, van knelpunten kan niet worden gesproken. De rammelstrook wat hoger aanleggen was wellicht een verbeterpunt

Hebt u verder nog ervaringen met de fietsstraat die u wilt delen?

Nee

Vragenlijst fietsstraat Venkelstraat

Waarom is besloten om de Venkelstraat in te richten als fietsstraat?

Maakt onderdeel uit van het fietsnetwerk zoals deze in het Haarlems Verkeers- en Vervoersplan staat (2003).

Welke functies heeft de fietsstraat? Denk aan woonstraat, hoofdfietsroute, wijkontsluiting, OV-route, winkelgebied.

Erftoegangsweg en fietsroute

Leidt de genoemde combinatie van functies tot knelpunten en zo ja, welke?

Voorrang regelen op een erftoegangsweg is eigenlijk tegenstrijdig met duurzaam veilig.

Wat is uw beeld als wegbeheerder over het functioneren van de fietsstraat? Positief/Negatief, waarom?

Positief, uit de enquete bleek dat de fietsstraat uiteindelijk goed is ontvangen door gebruikers en bewoners. Wel riep deze specifieke inrichting juridische onduidelijkheden op.

Wat is het beeld over het functioneren onder de gebruikers en aanwonenden? Zijn er klachten bekend? Is een evaluatieonderzoek beschikbaar?

Ja:
http://www.fietsberaad.nl/index.cfm?lang=nl&repository=Fietsstraat+Venkelstraat:+uitslag+gebruikersonderzoek

Zijn er intensiteiten bekend van langzaam en snelverkeer? Wat is de samenstelling van het snelverkeer? Is er een verdeling over de dag bekend?

-

Zijn er snelheidsmetingen uitgevoerd (evt. door de politie) na de realisatie van de fietsstraat? Zijn de resultaten daarvan beschikbaar?

-

Is het weggedrag op de fietsstraat zoals van te voren bedacht ten aanzien van:

a) Gemotoriseerd verkeer?
De automobilist moest in het begin wennen. Inmiddels weten de vaste gebruikers hoe dit werkt.

b) Langzaam verkeer?
Dit ontwerp laat de fietser in het midden fietsen. Dit durfde niet iedereen. Klacht is dat met dit ontwerp de fietser een auto die vlak achter je rijdt als bedreigend wordt ervaren.

c) Parkeren?
Voor haalbaarheid van het ontwerp is niet getornd aan het aantal parkeerplaatsen.

Hebben er sinds de opening ongevallen plaatsgevonden op de fietsstraat? Zo ja, wat voor soort ongevallen (eenzijdig, fiets-fiets, fiets-bromfiets, fiets-auto; frontaal, flank) en op welke locatie?

Naar mijn weten niet.

Waarom en hoe is gekozen voor een ontwerp met fietsers in het midden? (Aan de hand van een extern advies, een voorbeeld elders, eigen ontwerp?)

Voorbeeld elders.

Welke richtlijnen en/of publicaties zijn gebruikt om de vormgeving te bepalen?

Tekenen voor de Fiets (CROW)

Heeft u een ontwerptekening van de fietsstraat voor mij beschikbaar zodat ik daar de maatvoering uit kan afleiden?

-

Zijn na de opening nog aanpassingen verricht aan de fietsstraat om deze beter te laten functioneren? Zo ja, welke en waarom?

Naar aanleiding van de evaluatie is fietsasmarkering aangebracht.

Zijn er momenteel nog knelpunten op de fietsstraat bij u bekend? Waar bevinden zich deze?

Nee.

Hebt u verder nog ervaringen met de fietsstraat die u wilt delen?

Haarlem voert op zoveel mogelijk plekken nieuwe fietsstraten door, ter completering van het fietsnetwerk. Gekozen is om zoveel mogelijk dit ontwerp toe te passen. Naar mijn mening blijft een aandachtspunt dat alleen voor fietsstraat kan worden gekozen als er geen hoge intensiteiten van het autoverkeer is waar te nemen. De verhouding auto:fiets moet in het voordeel van de fiets zijn.

Vragenlijst fietsstraat Vondelkade

Waarom is besloten om de Vondelkade in te richten als fietsstraat?

De weg loopt door een 30 km/u gebied en was voorheen 8 meter breed. Om de hoofdfietsroute duidelijk te markeren is gekozen voor een fietsstraat:

- *profiel ondersteunt 30 km/u*
- *profiel is mn door rood asfalt duidelijk een belangrijke fietsroute*
- *profiel is smal waardoor meer ruimte voor groen; aantrekkelijk voor bewoners en fietsers*

Welke functies heeft de fietsstraat? Denk aan woonstraat, hoofdfietsroute, wijkontsluiting, OV-route, winkelgebied.

Woonstraat en hoofdfietsroute

Leidt de genoemde combinatie van functies tot knelpunten en zo ja, welke?

Nauwelijks knelpunten. Hooguit dat er wel eens dubbel geparkeerd (is nu altijd 1 persoon) wordt waardoor de rijbaan wel erg smal wordt.

Wat is uw beeld als wegbeheerder over het functioneren van de fietsstraat? Positief/Negatief, waarom?

Erg positief

Wat is het beeld over het functioneren onder de gebruikers en aanwonenden? Zijn er klachten bekend? Is een evaluatieonderzoek beschikbaar?

De fietsstraat ligt er nu bijna 10 jaar. Er zijn geen negatieve geluiden bekend onder bewoners en gebruiker. Wel weten we dat niet iedereen het gewenste gebruik snapt. Daarom werken wij nu al onze fietsstraten nagenoeg uitgevoerd zijn (we hebben er dan 8) aan een promotiecampagne.

Zijn er intensiteiten bekend van langzaam en snelverkeer? Wat is de samenstelling van het snelverkeer? Is er een verdeling over de dag bekend?

Heb je zelf met de telling nu voorhanden ….

Zijn er snelheidsmetingen uitgevoerd (evt. door de politie) na de realisatie van de fietsstraat? Zijn de resultaten daarvan beschikbaar?

Nee, er zijn geen gegevens beschikbaar

Is het weggedrag op de fietsstraat zoals van te voren bedacht ten aanzien van:

d) **Gemotoriseerd verkeer?**
Niet altijd, maar leidt niet tot klachten of overlast

e) **Langzaam verkeer?**
Langzaam verkeer wijkt nog wel eens uit naar de klinkerstrook om een automobilist die wil inhalen de ruimte te geven. Dit duidt er op dat men zich ondergeschikt voelt aan de auto, wat juist niet de bedoeling is.

f) Parkeren?
Zie eerder, het dubbelparkeren. Maar over het algemeen gaat het in de Vondelkade erg goed.

Hebben er sinds de opening ongevallen plaatsgevonden op de fietsstraat? Zo ja, wat voor soort ongevallen (eenzijdig, fiets-fiets, fiets-bromfiets, fiets-auto; frontaal, flank) en op welke locatie?

Nee.

Waarom en hoe is gekozen voor een ontwerp met fietsers in het midden? (Aan de hand van een extern advies, een voorbeeld elders, eigen ontwerp?)

Het is een eigen ontwerp, maar er is zeker gekeken naar ervaringen elders. Zwolle heeft gekozen voor de rabbat aan weerszijden en niet in de midden. Dit profiel minder weinig verhardingsbreedte ten opzichte van een rabbat die de rijrichtingen scheidt. Past meer in een woonstraat en geeft daardoor ruimte aan parkeren, groen of spelen.

Welke richtlijnen en/of publicaties zijn gebruikt om de vormgeving te bepalen?

??

Heeft u een ontwerptekening van de fietsstraat voor mij beschikbaar zodat ik daar de maatvoering uit kan afleiden?

Er is van de Vondelkade niet een bestekstekening gemaakt omdat het in het onderhoud mee ging.

Zijn na de opening nog aanpassingen verricht aan de fietsstraat om deze beter te laten functioneren? Zo ja, welke en waarom?

Nee, het is nog altijd ons beste voorbeeld van hoe ene fietsstraat er uit moet komen te zien

Zijn er momenteel nog knelpunten op de fietsstraat bij u bekend? Waar bevinden zich deze?

Alleen de oversteek bij de gebiedsontsluitingweg (Vechtsstraat-Wipstrikkerallee. Na de bouwvak wordt dit jaar daar een fietsrotonde aangelegd.

Hebt u verder nog ervaringen met de fietsstraat die u wilt delen?

De planvorming en de aanleg van een fietsstraat is altijd iets dat weer veel energie kost. Fietsstraten zijn bewoners bedreigend. Daarom heeft het veel uitleg en betrokkenheid in de planvorming van bewoners nodig. Tijdens uitvoering wordt aannemer vaak verrast door de overlast die hij heeft van fietsers. De routes zijn druk en het omleiden blijkt altijd weer moeilijk. Verder is de smalle rabbatstrook in het zwart lastig. De kwaliteit laat nogal eens te wensen over.

GLOSSARY

English term	**Dutch term**	**Explanation**
Crash	*Ziekenhuisongeval*	A traffic accident with one or more injured or deathly victim(s).
CROW	*CROW*	Dutch knowledge platform for infrastructure, traffic and transport.
Driving strip	*Rijloper*	In case of a bicycle street: part of the street meant for cyclists, mostly the asphalt part of the total pavement.
Grontmij	*Grontmij*	Second largest engineering consultancy in Europe and supporting company in this research.
Rabat strip	*Rabatstrook*	Element pavement along driving strip that provides extra space along the driving strip for large vehicles and evasive maneuvers.
Raised intersection	*Kruispuntplateau*	Traffic measure for lowering the speed of vehicles at intersections.
Road authority	*Wegbeheerder*	Owner of a particular street and responsible for the maintenance and reconstructions of this street. In this study is the road authority always the concerning municipality.
Road tube counter	*Telslang*	Device placed on the street for counting traffic and speeds of traffic.
Single-lane bicycle street	*Fietsstraat met fietsers meer in het midden*	Bicycle street with one driving strip in the middle and rabat strips along both sides.
Sustainable Safety	*Duurzaam Veilig*	Dutch vision on traffic safety, based on five main principles: functionality, homogeneity, predictability, forgivingness and state-awareness.
SWOV	*SWOV*	Dutch institute for Road Safety Research: knowledge and research institute for traffic safety in the Netherlands
Traffic engineer	*Verkeerskundige*	An expert in the field of the design of road infrastructure, traffic management and transport issues.
Traffic Space	*Verkeersruimte*	In this study: the space available of traffic in a profile, measured as the distance between the curbs.
Two-lane bicycle street	*Fietsstraat met middenberm*	Bicycle street with a driving strip per driving direction, separated by a median.
V85	*V85*	Driving speed not exceeded by 85 percent of the drivers on the bicycle street.