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Conflicting greens between straight-ahead cyclists and right-turning vehicles analysed, using naturalistic observations

Bachelor thesis proposal

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Preface

The bachelor thesis in front of you has been carried out for Goudappel Coffeng in Deventer. During the research for my thesis, I had help from many people. At first, I would like to thank Anika Boelhouwer for supporting and supervising me during my bachelor thesis. Among other things, she helped me to rectify the structure of this report, ameliorate my research questions and asked critical questions about the theoretical framework. Second my daily supervisor at Goudappel Coffeng, Rob de Wit, who primarily supported the practical side of my research and welcomed me at Goudappel Coffeng. Third the man without whom I would not have been able to perform my research; Nico van Beugen. He gathered, assembled and connected the road sign and flashing light needed for my naturalistic observations.

I enjoyed working at Goudappel Coffeng. Therefore I would also like to take the chance to thank all my colleagues at Goudappel Coffeng for their interest, support and time.

Abstract

Cyclists are the most vulnerable road users and the road users that are most frequently involved in an accident (Noord-Brabant, 2015; Centraal Bureau voor de Statistiek, 2017). Accidents between straight-ahead cyclists and right-turning motor vehicles are the most frequent accidents cyclists get involved in (Buch & Jensen, 2016). Despite several measures for vehicles, they fail to give priority to cyclists, because vehicle users fail to see cyclists (Kwan & Mapstone, 2004; Räsänen & Summala, 1998). With the vulnerability of the cyclist in mind Noord-Brabant (2015) came up with a plan for the purpose of zero deaths in 2020, as a result of traffic accidents. Because vehicles 'fail to see' and fail to give priority, cyclists have to be alarmed of the hazardous situation. Therefore, different measures were tested to see if the number of conflicts reduced. The measures were a road sign and a flashing light, both separately and the combination of the measures were tested. For these situations, the interactions between the vehicle and cyclist were analysed. In order to determine if cyclists were more aware of the dangerous situation, the number of times they looked aside was noted. The outcome of the test was remarkable; every situation had nearly the same number of conflicts. However, a cyclist looked more frequently aside for a vehicle for both the situation with only the flashing light and the combination of the flashing light and the sign. The situations with the flashing light and both the flashing light and the road sign resembled to have the same positive effect. The positive effect of a flashing light, for making road users aware of potential dangerous situations and drawing more attention to a sign, which is why also the combination of measures helped increase the times a cyclist looked aside, is in line with other papers. Although these clear indications are also supported by other research, more extensive reseach is needed for more firm conclusions. If this research is performed another time with longer observation times at multiple junctions, the benefits of warning a cyclist could contribute to a general measure for all conflicting greens between straight-ahead cyclists and right-turning vehicles and even contribute to the zero deaths target of Noord-Brabant (2015).

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Introduction

The past years traffic safety increased, unfortunately, the number of accidents with cyclists has not decreased as fast as for other road users. As a matter of fact the cyclist is, with a 17% share in victims of a traffic collision, the most vulnerable road user (Noord-Brabant, 2015). Additionally, in the Netherlands in 2016 even 30% of the fatal traffic victims was a cyclist (Centraal Bureau voor de Statistiek, 2017). Especially a right-turning road user that has a conflict with a straight ahead cyclist, is one of the most common occasions for an accident (Buch & Jensen, 2016). Such situations occur with conflicting greens in the Netherlands. In another leading cyclist country where these situations are common and more research is done, such as Denmark, accidents involving right-turning and straight-ahead road users occurred third most at signalised junctions. It concerned straight-ahead cyclists in almost all of these accidents. On top of that, accidents with cyclists are very underreported in Denmark, the real traffic accident numbers are probably higher (Buch & Jensen, 2016).

For the purpose of safer traffic, the province Noord-Brabant, in the Netherlands, presented a traffic safety plan. The main goal of this safety plan is zero deaths as a result of traffic collisions or accidents in 2020 (Noord-Brabant, 2015). In an attempt to improve cyclists' safety traffic, engineers have already designed different measures for these right-turning motorised vehicles and straight-ahead cyclists' conflicts. For instance the staggered stop line (stop line of motorised vehicles, usually 5 meters before the stop line of cyclists, to enhance the visibility of cyclists) or pre-green for cyclists. Also a warning sign or light was designed to attend motorised vehicles they must give priority to cyclists. Not all measures contributed to the overall safer crossing. For instance, the Danish Road Directorate (1994) concluded due to staggered stop lines the number of accidents decreased by 90% at the beginning of the green phase, but increased with 43% in the remaining part of the signal cycle. Despite these measures, accidents and conflicts still occur.

These measures are all from the perspective of motorised vehicles, whereas a consistent finding is that drivers fail to detect cyclists or detect them too late to prevent a collision (Kwan and Mapstone, 2004; Räsänen and Summala, 1998). This research focuses on finding a safety measure that creates awareness among cyclists for the dangerous situation they approach. Hence the effects of a warning sign or a flashing light for cyclists on conflicts will be investigated. The question arises how to create more awareness among approaching cyclists at a signalised junction with conflicting greens.

The main question is:

Does alerting cyclists by means of existing warning objects such as lights and signs of an approaching dangerous crossing help to reduce the risk of accidents at signalised junctions with conflicting greens?

To investigate the effects of the existing warning objects on cyclists' behaviour, a junction will be analysed for multiple days using the traffic conflict technique by Parker and Zegeer (1989) as a base. Besides conflicts, the focus will be on the behaviour of the cyclists with special attention to whether or not they looked over their shoulder, to check if a car approaches the conflict zone. The study is focused on the effects of a warning sign and a flashing light. These measures and their effects will be tested individually and in combination.

After the introduction the background information about conflicting greens and the related risks will be provided, for example by presenting relevant papers. Then the research design of the junction will be displayed together with the exact sign, flashing light, and used tables for interactions and conflicts used in this research. After the key variables are elaborated, the observed results will be presented according to the tables, which are filled in. Notable results will be pointed out. Next will be the basic conclusions based on these results. Subsequently, the discussion with strengths and weaknesses of the research and conclusions will follow. These will be elaborated and the connections with earlier research and papers is presented. To conclude with recommendations for further research for the core of this paper. The appendices with information about the analysed junction and some tables with filled in data is presented. At last the references will be presented.

Theoretical framework

In this part, the background information on the core concepts will be explained. These core concepts are: Risk of accidents, conflicting greens, conflict technique and naturalistic observation.

Core concepts

Risk of an accident

The most important variable to establish for this research is the risk of an accident, because it is the key measuring instrument for indicating an improvement or deterioration for the different measures on the signalised junction. The research is all about improving the safety, therefore accidents, conflicts, and interactions between cyclists and vehicles are the key performance indicators for the risk of an accident. The risk of an accident will be measured by three variables: first the differences in the number and severity of the accidents, then the conflicts will be compared, and after that the same comparison and tests will be performed for the interactions, these will be elaborated further in the subsection analysis of the methods section. Naturally the number of accidents and the number of conflicts are taken into account. However, also the interactions with special attention to the times cyclists look aside for a motorised vehicle is an important contributing factor. As mentioned in the introduction drivers fail to detect cyclists or detect them too late to prevent a collision. This implies a mistake by the driver that could end up as a conflict or an accident. It also suggests that cyclists' visibility on the road may be an important contributing factor to their crash involvement (Wood, Lacherez, Marszalek, & King, 2009). Though cyclists have priority in this situation, it is important to acknowledge the dangers of the situation and try to be more visible or check whether or not a right-turning vehicle is approaching the junction, because that could prevent a conflict or even an accident. Hence if a cyclists looks aside is an important factor for the risk of an accident. To measure these accidents, conflicts and interactions a conflict technique is used during a naturalistic observation at a junction with applied conflicting greens. These concepts will all be elaborated in the remainder of this chapter.

Conflicting greens

The main reason of this research are conflicting greens, without this concept the research would not have been performed. Conflicting greens imply conflicting travel directions that simultaneously receive a green signal at a junction. The purpose of accepting conflicting greens is: to cut total cycle time, more green for cyclists, and reduce red negation of road users. For instance, three types of conflicts are: straight ahead vehicles and left turning motor vehicles, all cyclists' simultaneously green, and straight ahead cyclists and right-turning motor vehicles. We accept these conflicts if for instance there is not enough space to enlarge the junction. In the Netherlands, no tough requirements for conflicting greens are imposed. However, many guideliness for an intersection with conflicting greens do exist: both conflicting directions should have enough sight, speeds on the intersection are low, the conflict must respond to the expected pattern of the concerned road users (no unlogical constructions), enough room on the junction for other cars to pass during waiting time, the design of the junction must be small, a maximum of two lanes of the approaching road, and low traffic intensity's (CROW, 2006).

As mentioned before conflicting greens have a significant share of cyclists' injuries, particularly straight-ahead cyclists conflicting with right-turning motorised vehicles. In this situation, vehicles should yield to cyclists, but they often fail to do so. In Sweden, like Denmark and the Netherlands another leading cyclist country, in only 73% of the cases drivers yield to cyclists (Svensson & Pauna-Gren, 2015). A consistent finding is that drivers do not detect cyclists or they detect cyclists too late to avoid a collision (Kwan and Mapstone, 2004; Räsänen and Summala, 1998). These "Looked-but-failed-to-see" events lead to not yielding, conflicts or even crashes. Which suggest shortcomings in driver attention processes (Brown, 2005). These shortcomings should not result in conflicts or even accidents.

Although conflicting greens are for instance designed to reduce red light negation and thus to enhance safety, a result of conflicting greens is a more unsafe junction. Because conflicting greens result in (accidents and) conflicts, conflict techniques are an important indicator to identify the junction´s safety and the risk of an accident.

Conflict techniques determine the demarcation line between a conflict and safe passing. Therefore, these techniques are excellent for measuring the number of conflicts and the dangerousness of a junction, however conflict techniques focus on cars, while this research focusses on cyclists. For this reason, a new 'conflict technique' will be used. Specifically, interactions between cyclists and motorised vehicles will be analysed as well.

Conflict technique

The conflict technique used in this research is a combination of different techniques with some additions. Two commonly accepted definitions of a conflict exist, others have based a conflict on video analysis techniques which were not at hand. The first definition of a conflict is that of Parker and Zegeer (1989). Their traffic conflict technique describes a conflict as: "an event involving two or more road users to make an evasive manoeuvre to avoid a collision" (p. 4). Second the DOCTOR method (Kraay et al., 1986). According to this method, a critical situation is a situation in which the available space for a manoeuvre is less than is needed for a normal reaction. If at least one of the parties involved needs to take action to avoid a collision, the situation is a conflict. These two methods are both often used for a naturalistic observation junction analysis, however these conflict techniques have been originally developed with ''cars in mind'', and some of the assumptions might not be accurate or are just incorrect (Laureshyn, de Goede, Saunier, & Fyhri, 2016). For instance it is normal cyclists do not follow a straight trajectory, but it could also look like an evasive manoeuvre, also only the DOCTOR method (Kraay et al., 1986) takes the potential consequences into account (Laureshyn, de Goede, Saunier, & Fyhri, 2016). Also the techniques only make an assumption about whether or not it is a conflict, while also the behaviour of the cyclists and the chain of events is important. As Laureshyn et al. (2016) concluded, a more comprehensive method for a better analysis of the situation and for more accurate record-keeping of the cyclists' reaction is essential for better insight in the severity of events. These techniques exist, but these are all automated and not at my disposal. As a result, the 'conflicts' will be manually categorised by a naturalistic observation.

Naturalistic observation

The observation of cyclists' behaviour was done through a naturalistic observation because that is an excellent way to observe behaviour in a natural way, it taps directly into the specific behaviour that is examined and fits perfectly the purpose of the research. The purpose is to observe and document the frequency of the different types of interactions of conflicts, this is more reliable to observe through visual inspection than analysing through an automated video technique, for instance because the categories are new (Eby, 2011).

Research questions

Does a road sign located at the stop line reduce the risk of an accident at a signalised junction with conflicting greens?

Charlton (2015) found that large dimension signs are nearly as effective as the VMS signs regarding their attentional visibility, but also found that it depends on the type of hazard. That means the efficiency of warning cyclists must be tested for this individual case, but it is expected less conflicts will occur for this measure due to better attention of the cyclists, which implies cyclists will look aside more often.

Does a flashing light located at the stop line reduce the risk of an accident at a signalised junction with conflicting greens?

Not much research is done concerning differences in hazard warnings. However, Charlton (2015) concluded flashing VMS warnings offer overall at least two beneficial effects. In comparison with a normal sign, a flashing warning should increase attentional visibility and appear to provide an advantage in communicating a hazardous situation to road users. It should at least make the cyclists more aware of the potential hazardous situation, which should result in less conflicts and more cyclists looking aside.

Does a combination of a road sign and a flashing light located at the stop line reduce the risk of an accident at a signalised junction with conflicting greens?
The VMS signs seemed to have an advantage as indicative of a potentially hazardous situation. Therefore the expectation is that in this case, due to the flashing light more cyclists will check the presence of a motorised vehicle than the other situations, because the flashing light will probably draw the cyclists´ attention to the sign. Therefore, the combination of both the sign and flashing light will probably reduce the risk of an accident more than the measures separated. Thus the hypothesis is both the number of conflicts will reduce the most and the number of cyclists who look aside will increase the most compared to the other situations.

Do cyclists adapt their behaviour after being warned for a potential dangerous junction?
The hypothesis is that cyclists will adapt their behaviour, because they will acknowledge the danger of conflicting greens. Additionally less conflicts will occur as a consequence of the cyclists´ behaviour, along with fewer interactions and cyclists will look aside more often.

Methodology

Does alerting cyclists (and mopeds) of an approaching conflict help to reduce the risk of accidents at signalised junctions with conflicting greens? How this research topic is investigated, is described in this section. Among other things the junction is explained, the tables, sign and flashing light are clarified and the situation at the junction for approaching cyclists is elaborated.

Study overview

This research, concerning conflicting greens, was carried out at the junction Brinkgreverweg – Henry Dunantlaan in Deventer. The situation is displayed and elaborated in Appendix A: with random straight-ahead cyclists and right-turning vehicles. The observation was done for four situations, which are shown in Table 1. To ensure the data was comprehensive enough each situation was observed and analysed for an hour and a half during three days. Situation one (S1) was observed before the pole with the measure(s) was placed. The frequencies obtained from the observations will be displayed later on in Table 1 for easy comparison and statistical tests. This pre-post method is chosen for ideal comparison between participants of different measures. During the naturalistic observation, behaviour of the cyclists and the conflict categories were also logged. These will be elaborated more detailed in the materials (next) section.

Table 1: Scheme with total conflict frequencies for the four test conditions

Situation	# Conflict	# Reference	Total
S1, normal situation			
S2, road sign			
S3, flashing light			
S4, light and sign			
Total			

Materials

To conduct the research, multiple attributes were required. For measuring the different situations both a road sign and a flashing light, Figure 1, are needed. Also a pole is needed to attach these measures, therefore an official traffic instrument is used (Nederlandse norm, 2010). This pole, displayed in Figure 2, is used in the Netherlands for different traffic regulations at junctions, for instance traffic lights. Therefore, it contributes to the credibility of the traffic measures. The required traffic measures are both legally accepted in the Netherlands and frequently used in Deventer (RVV 1990, 1990). This traffic sign and flashing light are both the VR09-1 sign, for the light the sign is reproduced but it has no specific code itself. Normally these signs are used to warn vehicles, but now they are placed next to the cycling path to warn cyclists. Because these are already being used to warn cars and due to limited time these measures are most unlikely to be misunderstood and so they are the best available options to warn cyclists.

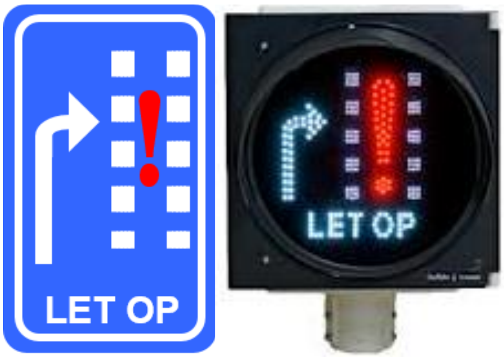


Figure 1 left the road sign VR09-1, 400 x 600 mm and right the flashing light based on the road sign VR09-1, 200 x 200mm

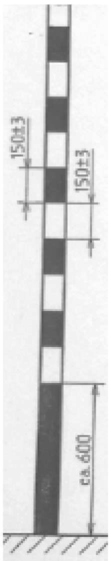


Figure 2 traffic pole used with specific dimensions in mm

The cyclists' reactions while approaching the conflict must be observed for four different scenarios. Therefore the two tables, Table 2 and Table 3, are made. The first table, Table 2, is used to analyse the interactions between cyclists and motorised vehicles. The number (#) a combination occurred is shown in the table. Also the percentage of the total number of interactions is displayed, just behind the number of times it occurred. Table 3 identifies the different sorts and seriousness of conflicts (Note: not all interactions automatically cause a conflict). Both tables are updated every day during the observation, with a distinction between cyclists who arrived and stopped on red before entering the junction and the cyclist who arrived on green. The demarcation between these scenarios is, because according to Buch and Jensen (2016) most conflicts occur at the middle and at the end of the green phase. If this theory is correct it would falsify the outcome when no difference between these situations is taken into account. Therefore, ´´stopped on red before entering the junction´´ is also represented for the different scenarios leading to a conflict. The research is performed in this manner to test earlier results of other researches and for a better comparison and view of the actual problem.

Table 2 categories of interactions between cyclists (vertical) and motorised vehicles (horizontal)

		Action of the straight-ahead motorised vehicles							
Action of the right-turning cyclists	**Interaction categories**	#Brake	%	#Slow down	%	#Keep going	%	#Do nothing	%
	Brake								
	Unroll								
	Do nothing specific/keep cycling								
	Accelerate								
	Look aside for motorised vehicle								

Table 3 the result for cyclists categorised during a conflict for different scenarios

		Different scenarios leading to a conflict		
Result for the right-turning cyclists	**Conflict categories**	Stopped on red before entering junction	'normal' conflict	No conflict
	Almost an conflict			
	Avoidance manoeuvre			
	Brake			
	Accident			

Variables

Dependent variables:

The most important dependent variable is the reaction of the cyclists on the test conditions. The possible reactions that will be distinguished by the analysis are: look aside for motorised vehicles, do nothing specific, unroll until they enter the junction, brake, and/or acceleration. One cyclist could also combine these. The number of conflicts is, besides important for the involved road users, another key performance indicator. The seriousness of a conflict will be categorised in; close, evasive manoeuvre, brake and an accident. These two will be the key performance indicators.

Independent variables:

The dependent variables will be measured (at first without a measure) with only a sign, only a light, and both a sign and a light. This is to determine which measure contributes most to safer crossing behaviour. For both the situation without a sign but with a flashing light and vice versa the measures could be misunderstood, confuse the cyclists, or be passed unnoticed. On the other hand could the situation with both the sign and the flashing light also confuse the cyclists of the purpose of the measure. However, if one of the measures functions enough, it is unnecessary to apply them both.

Protocol

Before cyclists enter the signalised junction, cyclists will encounter a road sign and/or a flashing light. This measure is located next to the bicycle path at the same height of the staggered stop line (for motorised vehicles) and draws the attention of the cyclist. The cyclists will notice the sign or they fail to notice the sign. Subsequently, if they saw the sign, cyclists may be alerted to the fact motorised vehicles simultaneously receive a green signal and thus are allowed to drive as well. Cyclists could check if they can cross safety or they do nothing specific at all. The reaction of the cyclists is recorded at the same time of their action. If the cyclists comes in a conflict with the right-turning vehicles, that is also logged.

Analysis

The results of the research will be analysed through a quantitative pre-post analysis. For multiple days of the same situation, the frequencies on specific combinations of behaviour is added up for both the conflicts, Table 1, the interactions, Table 2, and the conflict categories, Table 3. Then the scenario´s will be compared to each other using a chi-square test to verify if the results are significant, with special attention to the number of cyclists who look aside for a vehicle and the different types of conflicts. In this way the 'risk of an accident' is analysed, not only the number of conflicts are accounted for but also the behaviour of cyclists will be compared, but also the severity of the conflicts will be cross-referenced. Moreover, due to the naturistic observation, the cause of these conflicts is also known. In the next chapter, the results of the completed tables will be shown.

Results

This study includes 18 conflicts and 113 interactions, all between a cyclist and a motorised vehicle. These conflicts were observed during the observing periods of four different scenarios. Every scenario was observed for three days, which makes a total of 12 days observance. The observations took place in the afternoon rush and normally took about one hour to an hour and a half per day. In total 1246 cyclists passed the junction during the analyses, of which 1073 cyclists stopped on red before entering the junction, and 173 arrived receiving a green signal. Mopeds and cyclists are taken into one group during the analysis because the research is about the reaction and not about the speed cyclists or mopeds enter the junction. Also because it is inexact to measure the speeds and the distinction between cyclists and mopeds is not accurate, while for instance some e-bikes have a higher speeds than some mopeds. During the whole observation period none conflicts and almost none interactions arose while both parties stopped on red before entering the junction. Only one interaction occurred, this was because the cyclist failed to notice the green signal and the vehicles accelerated slowly to give priority to the cyclist. Consequently, (almost) all interactions and conflicts happened in the middle and at the end of the green phase. For this time in the green phase few conflicts happened, the result of all situations combined is shown in

Table 4. The table confirms the number of conflicts when both stopped on red before entering

		Different scenarios leading to a conflict		
	Conflict categories	Stopped on red before entering junction	'normal' conflict	No conflict
Result for the right-turning cyclists	Almost an conflict	0	6	0
	Avoidance manoeuvre	0	6	0
	Brake	0	6	0
	Accident	0	0	0

the junction and if the cyclists had to make a move it always resulted in a conflict. In appendix B, the conflicts are shown separately for all four situations.

Table 4 Conflict categories of cyclists: a total of 178 cyclists were analysed entering the junction on green

		Different scenarios leading to a conflict		
	Conflict categories	Stopped on red before entering junction	'normal' conflict	No conflict
Result for the right-turning cyclists	Almost an conflict	0	6	0
	Avoidance manoeuvre	0	6	0
	Brake	0	6	0
	Accident	0	0	0

Because of the limited conflicts the interactions between cyclists and motorised vehicles are more important. As described in the theoretical framework, the number of times cyclists look aside for a motorised vehicle is one of the most important data points. A total of 178 cyclists approached the junction on green, of which 113 cyclists had an interaction, shown in Table 5. In total 54 of the 113 that had an interaction looked aside for a motorised vehicle, which is 47.8% of the total. The difference between keep going and do nothing is based on the fact if motorised vehicles keep driving while a cyclist already stopped (on green) before entering the junction (keep going) or they actually keep driving while the cyclists is entering the junction (do nothing)

Table 5 Interactions between cyclists and motorised vehicles for all situations together

		Action of the straight-ahead motorised vehicles									
Action of the right-turning cyclists	**Interaction categories**	#Brake	%	#Slow down	%	#Keep going	%	#Do nothing	%	Total	%
	Brake	9	8,0%	1	0,9%	6	5,3%	5	4,4%	21	18,6%
	Unroll	5	4,4%	5	4,4%	5	4,4%	0	0,0%	15	13,3%
	Do nothing specific/ keep cycling	13	11,5%	6	5,3%	0	0,0%	0	0,0%	19	16,8%
	Accelerate	0	0,0%	4	3,5%	0	0,0%	0	0,0%	4	3,5%
	Look aside for motorised vehicle	9	8,0%	14	12,4%	5	4,4%	26	23,0%	54	47,8%
	Total	36	31,9%	30	26,5%	16	14,2%	31	27,4%	113	100,0%

The results will now be displayed per situation. The table with interactions between cyclists and motorised vehicles is presented and data that sticks out will be described.

Situation 1, normal situation

The interactions between cyclists and vehicles for the situation without any research measure is presented in Table 6: 24 cyclists had an interaction with a motorised vehicle for the normal situation

		Action of the straight-ahead motorised vehicles									
Action of the right-turning cyclists	**Interaction categories**	#Brake	%	#Slow down	%	#Keep going	%	#Do nothing	%	Total	%
	Brake	3	12,5%	0	0,0%	0	0,0%	0	0,0%	3	12,5%
	Unroll	2	8,3%	2	8,3%	0	0,0%	0	0,0%	4	16,7%
	Do nothing specific/ keep cycling	6	25,0%	4	16,7%	0	0,0%	0	0,0%	10	41,7%
	Accelerate	0	0,0%	2	8,3%	0	0,0%	0	0,0%	2	8,3%
	Look aside for motorised vehicle	1	4,2%	1	4,2%	2	8,3%	1	4,2%	5	20,8%
	Total	12	50,0%	9	37,5%	2	8,3%	1	4,2%	24	100,0%

. In 87.5% of the interactions vehicles gave priority to the cyclists by braking (50%) and decreasing their speed (37.5%) and in most cases cyclists were also able to continue cycling (41.7%). Cyclists looked aside for only 20.8% of the interactions.

Table 6: 24 cyclists had an interaction with a motorised vehicle for the normal situation

		Action of the straight-ahead motorised vehicles									
Action of the right-turning cyclists	**Interaction categories**	#Brake	%	#Slow down	%	#Keep going	%	#Do nothing	%	Total	%
	Brake	3	12,5%	0	0,0%	0	0,0%	0	0,0%	3	12,5%
	Unroll	2	8,3%	2	8,3%	0	0,0%	0	0,0%	4	16,7%
	Do nothing specific/ keep cycling	6	25,0%	4	16,7%	0	0,0%	0	0,0%	10	41,7%
	Accelerate	0	0,0%	2	8,3%	0	0,0%	0	0,0%	2	8,3%
	Look aside for motorised vehicle	1	4,2%	1	4,2%	2	8,3%	1	4,2%	5	20,8%
	Total	12	50,0%	9	37,5%	2	8,3%	1	4,2%	24	100,0%

Situation 2, road sign

For situation 2, less cars gave priority to cyclists, they braked 35.3% of the time and decreased their speed in 14.7% of the times and as a result cyclists were only able to continue cycling in 11.8% of the cases. They did look more often aside for a motorised vehicle (44.1%) and in 29.4% they looked aside while vehicles did nothing.

Table 7: 34 cyclists had an interaction with motorised vehicles for the situation with the road sign

		Action of the straight-ahead motorised vehicles									
	Interaction categories	#Brake	%	#Slow down	%	#Keep going	%	#Do nothing	%	#Total	%
Action of the right-turning cyclists	Brake	3	8,8%	0	0,0%	3	8,8%	3	8,8%	9	26,5%
	Unroll	2	5,9%	1	2,9%	1	2,9%	0	0,0%	4	11,8%
	Do nothing specific/ keep cycling	3	8,8%	1	2,9%	0	0,0%	0	0,0%	4	11,8%
	Accelerate	0	0,0%	2	5,9%	0	0,0%	0	0,0%	2	5,9%
	Look aside for motorised vehicle	4	11,8%	1	2,9%	0	0,0%	10	29,4%	15	44,1%
	Total	12	35,3%	5	14,7%	4	11,8%	13	38,2%	34	100,0%

Situation 3, flashing light

The first thing that stands out is that many cyclists looked aside in this situation, even in 60.5% of the interactions. Also the times cyclists are able to continue cycling is just 13.2%, while vehicles brake in 23.7% and decrease their speed in 34.2% of the interactions, which is together in 57.9% of the cases.

Table 8: 38 cyclist had an interaction with a motorised vehicle for the situation with the flashing light

		Action of the straight-ahead motorised vehicles									
	Interaction categories	#Brake	%	#Slow down	%	#Keep going	%	#Do nothing	%	Total	
Action of the right-turning cyclists	Brake	2	5,3%	0	0,0%	1	2,6%	2	5,3%	5	13,2%
	Unroll	1	2,6%	2	5,3%	2	5,3%	0	0,0%	5	13,2%
	Do nothing specific/ keep cycling	4	10,5%	1	2,6%	0	0,0%	0	0,0%	5	13,2%
	Accelerate	0	0,0%	0	0,0%	0	0,0%	0	0,0%	0	0,0%
	Look aside for motorised vehicle	2	5,3%	10	26,3%	1	2,6%	10	26,3%	23	60,5%
	Total	9	23,7%	13	34,2%	4	10,5%	12	31,6%	38	100,0%

Situation 4, road sign and flashing light

Just like situation 3, the number of times cyclists looked aside for a vehicle is high, in even 64.7% of the interactions cyclists checked for a vehicle. The number of times a vehicle kept going is with a 35.3% share roughly three times higher in comparison with the other situations.

Table 9: 17 cyclists had interactions with motorised vehicles for the situation with both the road sign and the flashing light

Action of the right-turning cyclists	Action of the straight-ahead motorised vehicles									Total	
	Interaction categories	#Brake	%	#Slow down	%	#Keep going	%	#Do nothing	%		
	Brake	1	5,9%	1	5,9%	2	11,8%	0	0,0%	4	23,5%
	Unroll	0	0,0%	0	0,0%	2	11,8%	0	0,0%	2	11,8%
	Do nothing specific/ keep cycling	0	0,0%	0	0,0%	0	0,0%	0	0,0%	0	0,0%
	Accelerate	0	0,0%	0	0,0%	0	0,0%	0	0,0%	0	0,0%
	Look aside for motorised vehicle	2	11,8%	2	11,8%	2	11,8%	5	29,4%	11	64,7%
	Total	3	17,6%	3	17,6%	6	35,3%	5	29,4%	17	100,0%

Situation comparison

The situations were analysed using a chi-square test for equality of proportions. The analysis was performed for both the interactions and the conflicts. First, for the interactions, then for the conflicts. The observed values for how many times a cyclist looked over his shoulder is presented in a 2×2 cross clarification table. Then the marginal distribution of the cyclists who looked aside and did not look aside are computed, see Table 10.

Table 10 2x2 table with observed values, O_i.

O_i	Situation 1	Situation 2	Total	Percentages
Looked aside	5	15	20	20/107=19%
Did not look aside	40	47	87	87/107=81%
Total	45	62	107	

Subsequently, with these marginal distributions, the expected value of the combined distribution is extrapolated to the individual columns, see Table 11.

Table 11 2x2 table with the expected values, E_i.

E_i	Situation 1	Situation 2	Total
Looked aside	45×19%=8	62×19%=12	20
Did not look aside	45×81%=37	62×81%=50	87
Total	45	62	107

Because the calculated chi-square value (χ^2, Eq. 1) has one degree of freedom, χ^2 must exceed 3.84, i.e. p≤0.05 for the safety measure to be statistically significant. It means the probability the differences between the observed (O_i) and expected (E_i) values are due to random variation is less than 5%. If the χ^2 is lower than 3.84, i.e. p≥0.05, the safety effect is not significant. The χ^2 values and corresponding p-values that were obtained, are shown in the following tables. First the P-value is calculated for the times a cyclists looked aside, because that is an important factor for the risk of an accident these are shown in Table 12. Only from situation 2 does not follow a significant increase of the times a cyclist looked aside. For both situation 3 and 4 the increase is significant and these situations are not a significant increase in cyclists who look aside relative to each other.

Table 12 results of the χ2-test of the different situations

Look aside	χ^2 Value	P-value	Significant?
S1 & S2	2,93641	0,086603	no
S1 & S3	28,39740	<0,00001	yes
S1 & S4	5,76613	0,016339	yes
S2 & S3	18,58056	1,60E-05	yes
S2 & S4	0,90506	0,341445	no
S3 & S4	8,73500	0,003122	yes

The same analysis was done for the conflicts of the different situations. Because the frequency of the different kinds of conflicts was too low, only the rough analysis for the total number of conflicts per situation was performed in stead of the difference per type of conflict, these are shown in Table 13. No situation has significant less conflicts than another situation.

Table 13 results of the χ2-test of the conflicts for different situations

Conflicts	χ^2 Value	P-value	Significant?
S1 & S2	0,0081	0.928287	no
S1 & S3	0,0532	0.817586	no
S1 & S4	0,0013	0.971238	no
S2 & S3	0,0212	0.884235	no
S2 & S4	0,0024	0.960927	no
S3 & S4	0,0340	0.853707	no

Results-research questions

In this section, the results of the interactions and conflicts will be interpreted and conclusions will be drawn. First, the sub-questions, concerning the different situations, will be answered, and then the main research question will be elaborated further according to the data of the interactions and conflicts.

Does a road sign located at the stop line reduce the risk of an accident at a signalised junction with conflicting greens?

According to the chi-square test for equality of proportions situation 1 and 2 do not significantly differ for both conflicts and interactions, so no indications are found a road sign helps cyclists to look more aside for a motorised vehicle compared to the normal situation. Therefore no indications have been found this sign helps reducing the risk of an accident.

Does a flashing light located at the stop line reduce the risk of an accident at a signalised junction with conflicting greens?

Compared to the normal situation the flashing light is a significant improvement considering if cyclists looked aside. The number of conflicts does not significantly differ from any other situation. Consequently, no indications have been found a flashing light reduces the number of conflicts, however some evidence a flashing light increases the number of times a cyclist looks aside has been found. Therefore indications have been found a flashing light contributes to a lower risk of an accident at this junction with conflicting greens.

Does a combination of a road sign and a flashing light located at the stop line reduce the risk of an accident at a signalised junction with conflicting greens?

The combination of measures (S4) is a significant improvement regarding the times a cyclist looked aside in comparison with the normal situation. Still, the number of conflicts does not significantly improve. So no indications are found the combination of a flashing light and a road sign reduces the number of conflicts, but it does look like the combination increases the times a cyclists looks aside. The combination of both measures indicates it might contribute to lower the risk of an accident.

Do cyclists adapt their behaviour after being warned for a potential dangerous junction?

All situations showed a significant improvement in cyclists looking aside, except just a road sign as a measure. In particular, a flashing light showed more cyclists looking aside. Consequently, indications have been found cyclists adapt their behaviour for a dangerous junction, if they are warned. The best way to warn cyclist seems to be by a flashing light combined with or without a sign.

Does alerting cyclists of an approaching conflict help to reduce the risk of accidents at signalised junctions with conflicting greens?

Despite cyclists seem to adapt their behaviour if being warned, the number of conflicts is not significantly different for other situations. But both situation 3 and 4 indicate cyclists look more aside, if warned by these measures. Thus indications are found alerting cyclists could help reducing the risk of a conflict at the analysed signalised junction.

Discussion

In the hypothesis the assumption was made cyclists would adapt their behaviour, which should result in more cyclists looking aside for right-turning vehicles and less conflicts. However, an outcome of the research was that none of the measures reduced the number of conflicts, which was not in line with the expectations, because according to (Charlton, 2015) a big warning sign is as effective as a flashing warning. Another outcome of the research is the flashing light and the combination of the flashing light and the road sign increased the times a cyclist looked aside for a vehicle, which is in line with the expectations. Charlton (2015) also found that flashing warnings offer two beneficial effects: increased visibility and a greater likelihood of being interpreted as indicative of a potential hazard (Charlton, 2015). Previous research also noticed that detection of road signs by drivers depend on their focus of attention (Hughes & Cole, 1986; Martens, 2000). This also supports the observation that cyclists became more aware of the hazard with a flashing light as a measure. A notable result is that a flashing light in combination with a road sign does not significantly reduce the number of conflicts and does not significantly increase the number of times cyclists look aside. Summala and Hietemaki (1984) found that placing a flashing light on top of a sign reduced the speed of a vehicle, except for people who did not feel they constituted a hazard. One explanation could be cyclists did not feel they approached a hazard. Another explanation is that because of the many signs these days people fail to notice hazard signs, which makes the combinations of the sign and a flashing light less conspicuous than only the flashing light.

The first thing from these results to notice are the interactions and conflicts of the cyclists who stopped on red before entering the junction. Almost every time multiple cyclists stopped on red together. This suggests staggered stop lines prevent conflicts at the beginning of the green phase and strengthens the 'safety in numbers' principle as proposed by Buch and Jensen (2016).

During the naturalistic observation a remarkable tendency was observed. Once right-turning motorised vehicles were driving, they did not seem to understand they have to give way to cyclists, which resulted in small gaps between cars for crossing cyclists. Consequently, cyclists arriving during green had two options; stop on green or cross between the cars. The last option obviously resulted in conflicts. The observations made in this research do suggest however, the actions of the cyclists did change and they are more aware of the hazard.

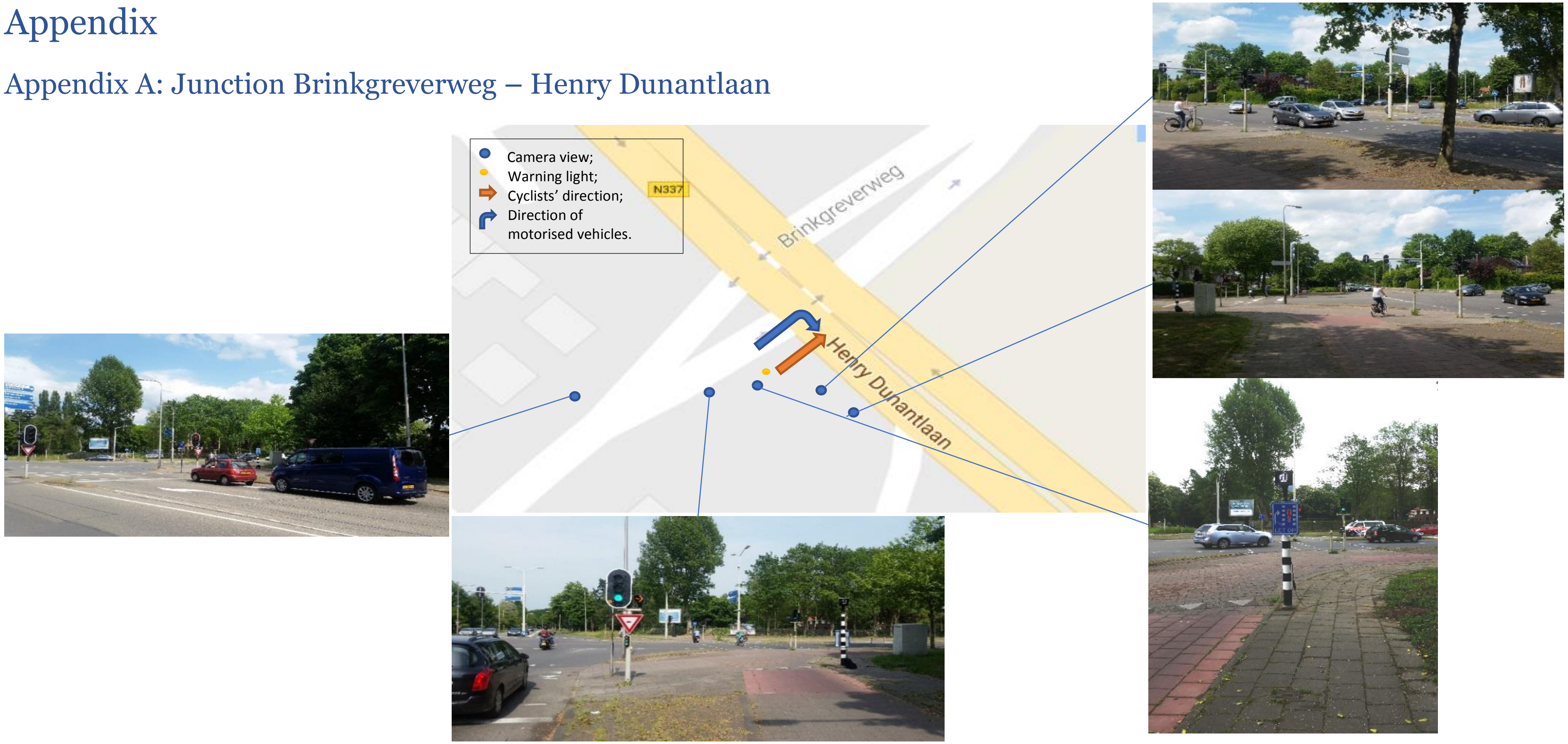
The limitations of the conducted research have to be noted in reflecting on the conclusions drawn from the observations It does give indications and general directives. However, hard conclusions can't be drawn on the current dataset, because the number of conflicts is too limited and the research is done for only one junction. With the extension of the observation periods and thus increased number of the conflicts collected such analysis might be feasible. This research was more exploratory, because it was difficult to take all aspects of different designs of conflicting greens into consideration within limited time to come up with a general outcome. To come up with a result that is useful in all or at least multiple right-turning vehicles conflicting with straight-ahead cyclists is questionable due to the different situations. But, with the period used in this study, 3 working days, we can conclude the number of conflicts is still quite low if split by type. Also, other intersections have to be analysed to draw a firm conclusion about the working of the hazard warning sign and flashing light.

Recommendation

Several variables could be usefully explored further to reject or confirm some results of this research. For instance the beneficial effects of a flashing light and the combination of the flashing light and the road sign should be investigated further. Also the possible beneficial effects of the location of the measures, if they are placed more close to the stop line for cyclists should be investigated. In further research also other ways than a road sign or a flashing light should be considered to reduce conflicts in the middle and the end phase. Interviewing different parties facing dangerous junctions might be effective for that as well. It is questionable to use a traditional naturalistic accident study for the small number of right-turn conflicts again due to the high labor-intensity, however this was an excellent and easy way to test if more research in this direction could contribute to make conflicting greens safer. For further research video analysis techniques is useful to investigate more different junctions and multiple other measures at the same time. Also, the effects of road safety education about conflicting greens must be investigated on the long term, because cyclists should be more aware of the hazardous situation.

Appendix

Appendix A: Junction Brinkgreverweg – Henry Dunantlaan



The location of this junction is in the built-up area of Deventer. With the specific examined conflicting greens, the straight-ahead cyclists (orange arrow) cross a provincial road. The place cyclists have to stop before entering the junction is a transparent place, so right-turning vehicles will probably notice them. There are also multiple warning systems for right-turning vehicles: next to the green light a flashing arrow is displayed and after turning right, both left and right of the conflict area with the cyclist a flashing triangle is shown.

Appendix B: conflict categories

Table 14 the different sorts and numbers of conflicts per situation.

Situation 1, normal		Different scenarios leading to a conflict		
Result for the right-turning cyclists	**Conflict categories**	Stopped on red before entering junction	'normal' conflict	No conflict
	Almost an interaction	0	1	0
	Avoidance manoeuvre	0	2	0
	Brake	0	2	0
	Accident	0	0	0
Situation 2, road sign		Different scenarios leading to a conflict		
Result for the right-turning cyclists	**Conflict categories**	Stopped on red before entering junction	'normal' conflict	No conflict
	Almost an interaction	0	1	0
	Avoidance manoeuvre	0	2	0
	Brake	0	2	0
	Accident	0	0	0
Situation 3, flashing light		Different scenarios leading to a conflict		
Result for the right-turning cyclists	**Conflict categories**	Stopped on red before entering junction	'normal' conflict	No conflict
	Almost an interaction	0	2	0
	Avoidance manoeuvre	0	1	0
	Brake	0	1	0
	Accident	0	0	0
Situation 4, sign and light		Different scenarios leading to a conflict		
Result for the right-turning cyclists	**Conflict categories**	Stopped on red before entering junction	'normal' conflict	No conflict
	Almost an interaction	0	2	0
	Avoidance manoeuvre	0	1	0
	Brake	0	1	0
	Accident	0	0	0

References

Billot-Grasset, A., Amoros, E., & Hours, M. (2015). How cyclist behavior affects bicycle accident configurations? *Elsevier*, 271.

British Medical Association. (1992). Cycling Towards Health and Safety. *Oxford University Press*.

Brown, I. (2005). Reviewof the 'Looked but Failed to See' Accident Causation Factor. *Department for transport*.

Buch, T. S., & Jensen, S. U. (2016). Incidents between straight-ahead cyclists and right turning motor vehicles at signalised junctions. *Elsevier*, 5-7.

Centraal Bureau voor de Statistiek. (2017). *Overledenen; doden door verkeersongeval in Nederland; wijze van deelname*. Retrieved from Centraal Bureau voor de Statistiek: http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=71936NED&D1=a&D2=0&D3=a&D4=l&HDR=G3%2cG2%2cG1&STB=T&VW=T

Charlton, S. G. (2015). Conspicuity, memorability, comprehension, and priming in road hazard warning signs. *Accident Analysis and Prevention*, 496-506.

Chataway, E. S., Kaplan, S., Nielsen, T. A., & Prato, C. G. (2014). Safety perceptions and reported behavior related to cycling in mixed traffic: a comparison between Brisbane and Copenhagen. *Transportation Research Part F: Traffic Psychology and Behaviour*.

CROW. (2006). *Handboek verkeerslichtenregelingen*. Ede: CROW.

Danish Road Directorate. (1987). *Accidents between straight-ahead cyclists and right-turning car drivers*. Copenhagen.

Danish Road Directorate. (1994). *Cyclists' safety in urban areas*. Copenhagen.

Danish Road Directorate. (2011). *Accidents at signalized junctions 2001-2010*. Copenhagen.

Danish Road Directorate. (2014). *Fatal accidents 2012*. Copenhagen.

Eby, D. W. (2011). Naturalistic Observational Field Techniques for Traffic Psychology research. In B. E. Porter, *Handbook of Traffic Psychology* (pp. 61-64). San Diego: Academic Press.

Federal Highway Administration. (2005). Safety Evaluation of Red-Light Cameras. *Research, Development, and Technology*.

Garder, P., Leden, L., & Pulkkinen, U. (1998). Measuring the Safety Effect of Raised Bicycle Crossings Using a New Research Methodology. *Transportation Research Record 1636*, 64-70.

Gatersleben, B., & Appleton, K. M. (2007). Contemplating cycling to work: Attitudes and perceptions in different stages of change. *Transportation Research Part A: Policy and Practice*, 302.

Heinen, E., van Wee, B., & Maat, K. (2010). Commuting by Bicycle: an overview of the literature. *Transport review*, 59-96.

Hughes, P. K., & Cole, B. L. (1986). What attracts attention when driving? *Ergonomics*, 377-391.

Kraay, H. J., & van der Horst, A. R. (1988). *De Nederlandse conflictobservatietechniek "DOCTOR"*. Leidschendam: Stichting Wetenschappelijk Onderzoek Verkeersveiligheid.

Kwan, I., & Mapstone, J. (2004). Visibility aids for pedestrians and cyclists: a systematic review of randomised controlled trials. *Accident Analysis & Prevention*, 305-312.

Laureshyn, A., de Goede, M., Saunier, N., & Fyhri, A. (2016). Cross-comparison of three surrogate safety methods to diagnose cyclist safety problems at intersections in Norway. *Accident Analysis and Prevention*.

Mantuano, A., Bernardi, S., & Rupi, F. (2016). Cyclist gaze behavior in urban space: an eye-tracking experiment on the bicycle network of Bologna. *Case Studies on Transport Policy*.

Martens, M. H. (2000). Assesing road sign perception: a methodological review. *Transportation Human Factors*, 347-357.

Meurs, H. v. (2017, 02 10). *Ontruimingslicht*. Retrieved from Hans van Meurs: http://www.hansvanmeurs.eu/richtung/index.php

Nederlandse norm. (2010). *NEN 3322*. Delft: Nederlands Normalisatie Insitituut.

Noord-Brabant. (2015). *NUL Verkeersdoden Brabant*. Retrieved from Brabant gaat voor nul verkeersdoden: https://www.nulverkeersdodenbrabant.nl/

Ogilvie, D., Egan, M., Hamilton, V., & Petticrew, M. (2004). Promoting walking and cycling as an alternative to using cars: systematic review. *BMJ*, 329.

Parker, M. R., & Zegeer, C. V. (1989). *Traffic conflict techniques for safety and operations: Observers manual*. Washington, DC: Federal Highway Administration.

Räsänen, M., & Summala, H. (1998). Attention and expectation problems in bicycle–car collisions: an in-depth study. *Accident Analysis & Prevention*.

RVV 1990. (1990, July 26). Retrieved June 27, 2017, from http://wetten.overheid.nl/BWBR0004825/2017-01-01

Schepers, J., & Voorham, J. (2010). *Oversteekongevallen met fietsers*. Rijkswaterstaat Dienst Verkeer en Scheepvaart .

Schepers, P., Hagenzieker, M., Methorst, R., van Wee, B., & Wegman, F. (2014). A conceptual framework for road safety and mobility applied to cycling safety. *Accident Analysis & Prevention*.

Schoon, C., Doumen, M., & De Bruin, D. (2008). The circumstances of blind spot crashes and short- and long term measures. *Stichting Wetenschappelijk Onderzoek Verkeersveiligheid*, 7,8.

Summala, H., & Hietamäki, J. (1984). Drivers' immediate responses to traffic signs. *Ergonomics 27(2)*.

Svensson, A., & Pauna-Gren, J. (2015). Safety at cycle crossings: The relationship between motor vehicles yielding behaviour and cyclists' traffic safety. *Proceedings of 28th ICTCT Workshop in Ashdod*.

Tran, C., Bark, K., & Ng-Thow-Hing, V. (2013). A Left-Turn Driving Aid Using Projected Oncoming Vehicle. *AutomotiveUI*, 300.

Wegman, F., Zhang, F., & Dijkstra, A. (2012). How to make more cycling good for road. *Accident Analysis & Prevention*.

Wood, J. M., Lacherez, P. F., Marszalek, R. P., & King, M. J. (2009). Drivers' and cyclists' experiences of sharing the road: Incidents, attitudes and perceptions of visibility. *Accident Analysis and Prevention*.

Zeegers, T. (2004). *Alle Fietsers Tegelijkertijd Groen bij verkeerslichten* . Retrieved from Fietsberaad.