A comparison between the pleintje, priority intersection & roundabout

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A comparison on cyclist traffic safety, traffic flow and environment.

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A comparison between the pleintje, priority intersection and roundabout based on the criteria cyclist traffic safety, traffic flow and environment.

pleintje, priority intersection, roundabout, voorraansplein, comparison, cyclist, traffic safety, conflict
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Preface

This is the final report of my graduation thesis. This thesis will be the final chapter during my study of Civil Engineering at the TU Delft. During my study, I've eventually chosen for the master Transport and Planning. This master focuses mainly on traffic management, both for road and rail transport.

In light of this master, my final graduation project is related to this aspect, hence the title of this thesis being *A comparison between the pleintje, priority intersection & roundabout, A comparison on cyclist traffic safety, traffic flow and environment*. This study consists of a comparison between a new type of intersection, the pleintje, against traditional intersection designs like the priority intersection and the roundabout. Comparing them on the aspects of traffic safety, traffic flow and environment.

During my thesis, I was able to perform my tasks within the corporation of Goudappel Coffeng. They are the original developers of the pleintje and have both the knowledge and tools that proved to be invaluable to my research. Next to that, they allowed me to take a look at their other work while I was working with them. I would like to thank them for this opportunity and the support I have received. In special I like to thank Rico Andriesse, who acted as my daily supervisor and Harry Groot, with whom I have had numerous chats about both my own thesis as well as other projects going on within the company.

Next I would like to thank the other members of my graduation committee, Fred Wegman, Paul Wiggenraad, Jan Anne Annema and Atze Dijkstra. They all provided advice about the thesis in general as well as their expert opinion about certain aspects of the study. Next to them, a special thanks to Edwin Scharp, who spend a good number of days in the field with me, observing the different intersections with the help of his cameras and other equipment. And also my gratitude to the municipalities of Heerhugowaard and Purmerend who allowed us to observe in their towns.

Last but not least, I want to specially thank my family, who provided me with the means and support to finish this thesis as well as my entire study.

Erwin van der Leeden
Veenendaal, April 2013
Summary

This thesis consists of a study about intersection designs, namely the roundabout, priority intersection and the pleintje. Pleintjes are a new type of intersection, which has recently been re-introduced and is now being build more and more as an alternative to the roundabout and priority intersection. However, this has lead to numerous discussions and questions about the use of this intersection, mainly because of a general lack of knowledge about the pleintjes functioning in practice.

With more municipalities (considering) building pleintjes in their town, some interest appears to have a study about the pleintjes. This study makes use of this, by analyzing not only the pleintjes, but also comparing them to a priority intersection and a roundabout. In order to compare these three intersections criteria have been selected, namely traffic safety, traffic flow and environment.

In order to receive some proper parameters for comparison, data was gathered in two different ways. With the main emphasis of this study lying on the traffic safety aspect, a large part of time was spend researching this area. Crash analysis can't give any good results, since the documentation of crashes has seriously decreased in recent years. Next to this, crash analysis is usually done by analyzing years of data. Since pleintjes have only been build recently, this data is simply not available yet. Therefore it was decided to use a conflict observation technique instead, observing conflicts in order to get some insight into the risk of a crash. With fatalities and injuries amongst cyclists not decreasing in recent years, while other traffic groups are decreasing, it was decided to focus this study on the conflicts between crossing cyclists and passing cars.

During six days, two pleintjes, two roundabouts and two priority intersections have been observed using cameras. Afterwards, these videos have been reviewed and all encounters, conflicts and critical conflicts have been characterized on a few parameters like driving direction, priority rules, evasive manoeuvres, etc. The video has also been used to determine the average speed of cars passing the conflict area. This is also important for traffic safety as a higher speed leads to a higher chance of a fatal injury. Basically, the conflicts give an indication to the risk of a crash, as more (critical) conflicts will most likely lead to more crashes in the long run. The speed measurement gives a good indication as to the effects if a crash happens.

Next to these camera observations a simulation tool was used to determine parameters for the traffic flow and environment. The results from these simulations, as well as the data from the conflict observations and speed measurements are all used to compare the different intersections in a MCA based on six criteria. These criteria are the following.
• Number of Critical Conflicts per car, per bike.
• Chance of a fatal crash based on the average speed.
• CO₂ emission per car.
• PM₁₀ emission per car.
• Waiting time per car.
• Waiting time per cyclist.

Based on these criteria a comparison is made. In the first comparison each criteria is weighed equally. For the second comparison, each criteria has given a certain weight to it, using the CBA indicators from Rijkswaterstaat to express these parameters in a monetary value. Based on the results from the data and the final comparison, an answer is found on the research questions.

The main research question in this study was the following: How does the traffic safety of the pleintje, priority intersection and roundabout compare with each other? After reviewing all the data no 'safest' intersection could be pointed out. This is caused because of the large variation in the results from the conflict observations. However, two points could be made though. First off all, it appeared that if an encounter takes place, the chance it becomes a (critical) conflict is larger at a roundabout compared to a pleintje. Priority intersection results are inconclusive on this aspect. Second, the severity of a possible crash is lowest at the roundabout due to the lower speed compared to the pleintje and priority intersection, which on their turn do not differ much even though the pleintje ranks slightly better.

Finally, only two of each intersection has been observed, which hardly allows general conclusions to be made. However, this study does give a first indication to possible results after more intersections have been studied. It also provides a manual as to how further research could be set-up, using the methods described and used for this study, as well as test these methods in practice.
Samenvatting

Deze scriptie bestaat uit een studie naar kruispuntoplossingen, namelijk de rotonde, voorrangskruispunt en het voorrangspleintje. Voorrangspleintjes zijn een nieuw kruispunttype, welke recentelijk zijn opnieuw zijn geïntroduceerd. Tegenwoordig worden er steeds meer aangelegd als een alternatief voor de rotonde en voorrangskruispunt. Dit heeft er mede voor gezorgd dat er flink wat discussie en vragen zijn ontstaan over het gebruik van dit voorrangspleintje, voornamelijk vanwege een gebruik aan kennis over de werking van dit voorrangspleintje in de praktijk.

Omdat steeds meer steden er over nadenken om deze voorrangspleintjes aan te leggen of dit zelfs al hebben gedaan, blijkt er belangstelling te zijn voor onderzoek naar deze pleintjes. Dat is dan ook wat deze studie doet, niet alleen door de pleintjes te analyseren, maar deze ook te vergelijken met een voorrangskruispunt en een rotonde. Voor deze vergelijking zijn criteria geselecteerd, namelijk verkeersveiligheid, doorstroming en milieu.

Om aan goede parameters voor de vergelijking te komen, is er op twee verschillende manieren informatie verzameld. Omdat de nadruk van dit onderzoek ligt op de verkeersveiligheid, is de meeste tijd gaan zitten in dit onderdeel. Ongevallenstatistiek levert geen bruikbare resultaten op, omdat het documenteren van ongevallen de laatste jaren flink is teruggelopen. Daarnaast wordt ongevallenstatistiek vaak toegepast op jaren aan data. Aangezien voorrangspleintjes pas sinds kort worden aangelegd is deze data simpelweg nog niet beschikbaar. Daarom is er voor gekozen om een conflict observatietechniek te gebruiken, waarmee via de observatie van conflicten een inzicht is gekregen in het risico op een ongeluk. Aangezien het aantal ongevallen met fietersers de laatste jaren niet gedaald is, is er bij deze studie voor gekozen om te richten op de conflicten tussen overstekende fieters en auto's die hun weg kruisen.

Gedurende zes dagen zijn twee voorrangspleintjes, twee rotondes en twee voorrangskruispunten geobserveerd met behulp van camera's. Naderhand zijn deze beelden bekeken en alle ontmoetingen, conflicten en kritische conflicten zijn gekenmerkt op onderdelen als rijrichting, voorrangssituatie, ontwikkende handelingen, enz. De beelden zijn tevens gebruikt voor snelheidsmetingen. Dit is namelijk ook een belangrijk onderdeel voor de verkeersveiligheid aangezien een hogere snelheid leidt tot een hogere kans op een dodelijk ongeval. In feite geven de conflicten een indicatie naar de kans op een ongeval, aangezien meer (kritische) conflicten waarschijnlijk ook leidt tot meer ongevallen op de lange termijn. De snelheid aan de andere kant geeft een goede indicatie van de gevolgen als er een ongeluk gebeurt.
Behalve de camera observaties is er ook een simulatie programma gebruikt om de parameters voor doorstroming en milieu te bepalen. De resultaten van deze simulaties, alsmede de data van de conflictobservatie en de snelheidsmeting, worden gebruikt om de verschillende kruispunten in een MCA te vergelijken op bases van zes criteria. Dit zijn deze criteria.

- Aantal kritische conflict per auto, per fiets.
- Kans op een dodelijk ongeval op basis van de snelheid.
- CO2 uitstoot per auto.
- PM10 uitstoot per auto.
- Gemiddelde wachttijd per auto.
- Gemiddelde wachttijd per fiets.

Op basis van de criteria is de vergelijking gemaakt. Bij de eerste vergelijking is elk criteria even zwaar meegewogen. Bij de tweede vergelijking heeft elk criteria een bepaald gewicht gekregen. Door het gebruik van de KBA indicatoren van Rijkswaterstaat zijn de criteria uitgedrukt in een geldwaarde. Op basis van de gevonden data, alsmede deze twee vergelijkingen, is uiteindelijk een antwoord gevonden op de verschillende onderzoeksvragen.

De hoofdvraag van dit onderzoek was: Hoe verhoud de verkeersveiligheid van het voorrangspleintje, voorrangskruispunt en rotonde zich met elkaar?
Na alle data bestudeerd te hebben, was het niet mogelijk om een 'veiligste' kruispunt oplossing aan te wijzen. Dit komt vooral door de variaties in de conflictobservatie. Toch kunnen er op het eerste gezicht twee punten uitgepikt worden. Ten eerste lijkt het erop dat als er een ontmoeting plaats vind, dit bij een rotonde eerder tot een (kritisch) conflict leid dan bij een voorrangspleintje. De resultaten voor het voorrangskruispunt gaven geen duidelijk beeld op dit aspect. Ten tweede, de ernst van een mogelijk ongeval is het laagst op een rotonde vanwege de lagere snelheid in vergelijking met het voorrangspleintje en voorrangskruispunt. Deze twee scoren min of meer gelijkwaardig op dit aspect, hoewel het pleintje iets beter lijkt te zijn.

Tot slot, er zijn twee kruispunten van elk type geobserveerd waardoor het eigenlijk niet mogelijk is om algemene conclusies aan dit onderzoek te verbinden. Toch geeft dit onderzoek een eerste indicatie van de mogelijke resultaten zodra meer kruispunten zijn onderzocht. Daarnaast geeft het een handleiding voor de opzet van volgende onderzoeken naar dit onderwerp. Welke methoden kunnen gebruikt worden, alsmede een eerste test naar het daadwerkelijk gebruik van deze methoden.
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This first chapter is an introduction to the thesis. What are the reasons for this thesis as well as the subject. Finally a reading guide for this report will be given.

1.1 Introduction

In recent years, an old design philosophy has been reintroduced on the Dutch road network. First developed in the nineties, the Largas method tried to achieve a more homogenous traffic flow, reducing emissions. After being put back on the shelve for a few years, it was later reintroduced. With a slightly different marketing approach, the pleintje, the Largas’ intersection solution, is also used on its own and considered as a proper alternative in intersection design. First being implemented in Hilversum, slowly other municipalities are also considering and building pleintjes.

The construction of these pleintjes opens up brand new possibilities for evaluations and research. Previous concerns and questions regarding this design were only answerable by theories and simulations, if answerable at all. This contrary to other types like the roundabout, of which many have been build and studied already. With the construction of these pleintjes, an actual study regarding the functioning of these pleintjes in practice is now also a possibility, just like the other types. This study makes full use of this new situation. It uses both the simulations as well as traffic observations, to make a comparison between the pleintje, priority intersection and roundabout based on the aspects traffic safety, traffic flow and environment.

As mentioned above, this study focuses on three different types of intersections, namely the pleintje, the priority intersection and the roundabout. More specific, intersections between a distributor road and an access road within city boundaries which have separated bicycle tracks. This last aspect is a key element as the traffic safety aspect of the study focuses primarily at the conflicts between crossing cyclists and passing cars. With the use of camera observation an indication is given about this cyclist traffic safety. Traffic simulations are used to gain insight into the traffic flow and environment parameters. All together, this study aims to compare the different designs, or at the very least provide a research method for further studies.
1.2 Reading guide

The first chapter gives a short introduction as well as the reading guide. The second chapter gives an analysis of the current problems surrounding the pleintje. It describes what questions are still to be answered, eventually leading into a problem definition as well as the research questions for this thesis. The third chapter gives an overview of the literature and theoretical background of the different subjects which will be dealt with during this study. The fourth chapter describes the different methodologies used, as well as the related choices which have been made in order to perform this study. The next chapter gives an overview of the data collection and a first analysis of this data, both for the camera observations and the simulations. The sixth chapter uses all this data and analysis to make a final comparison between the different intersections based on the three main criteria. Chapter seven is an evaluation of the project. The final chapter draws the conclusions, gives an answer to the research questions and hands out some recommendations for future research regarding this subject.

As for now, the next chapter will first go into depth as to what this study aims to do. What is the problem and what questions need to be answered in order to (partially) solve this problem. Hence, the research questions for this study will be presented.
Chapter two will give an outline of the research project. It will start off with an analysis of the problem. Followed by what this analysis means for the study and what will be the main objective this study will try to achieve. Last but not least, the research questions for this thesis will be presented.

2.1 Problem analysis

The Pleintje is a relative new intersection design which is currently being used in practice more and more. However, compared to roundabouts and priority intersections, only a handful have been build. Which immediately leads to one of the biggest problems, the lack of practical experience with the pleintjes. Roundabouts and priority intersections are plentiful in both the Netherlands, as well as other countries. Therefore, numerous studies have been performed on them, with both theoretical and practical approaches. For the pleintje, the latter has not been done yet. Therefore, both proponents and opponents have to base their opinions mainly on the theory.

However, in recent years, several municipalities have been convinced to try out this new intersection design and there are now a fair number of pleintjes either already finished or in development. This will give the opportunity to analyze the functioning of the pleintje in practice and possibly fill in some of the knowledge gaps that still exist today. Not only this, but it also gives the opportunity to compare the pleintje with the traditional intersection types, the roundabout and the priority intersection.

2.1.1 Traffic speed
One of the most debated aspects of this intersection design is the speed of which vehicles are allowed to pass. The design aims to give right of way to the main traffic stream, allowing them to pass the intersection almost uninterrupted. Even though (design) precautions are implemented to reduce the speed at the intersection itself, initial evaluations\(^5\)\(^6\) show that the measured speeds are above the design speed. In itself, this does not have to be a problem, as there are many other factors which contribute to possible crashes for example, but speed is one of the most important contributors\(^7\). Therefore, opponents gladly use these first evaluations to crack the pleintje and promote the implementation of a roundabout instead. As the design of the roundabout does force all drivers to slow down before passing the intersection. However, current conclusions are based on only one or two evaluations and could therefore hardly be considered to be a general result for all pleintjes. With the addition of more pleintjes, the option becomes available to research the speed at other locations as well and check if the initial evaluations appear correct or not.

2.1.2 Traffic safety
Linked to the speed issue, are the concerns about traffic safety. In the past, the priority intersection has had its fair amount of traffic crashes. Therefore, the roundabout was implemented, which had a significant positive effect on traffic safety\(^8\). With the introduction of the pleintje, opponents believe that the achieved safety effects will be undone. Less speed reduction, higher speeds, more conflicts. They are all supposed to decrease traffic safety, or increase the effect when a crash does happen. (i.e., a higher speed increases the chance of serious injuries or even death) However, the mentioned speed is not the only contributor. So just drawing conclusions about traffic safety based on a higher speed may be a bit short-sighted. Other aspects like priority rules (on roundabouts cyclists usually have priority, while the choice has been made not to give cyclists priority on pleintjes), conflict points as well as general behaviour. It is not known if these aspects are the same or different when comparing the pleintje to the more traditional intersections. As well as how they contribute to the general traffic safety of the pleintje in specific.

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\(^7\) SWOV (2012). SWOV-Factsheet De relatie tussen snelheid en ongevallen. Stichting Wetenschappelijk Onderzoek Verkeersveiligheid SWOV, Leidschendam.

2.1.3 Traffic flow
Next to traffic safety, the possible higher speed for traffic on the main road, will also influence the traffic flow. Constructing a roundabout makes all branches of the intersection equal. In practice however, there usually is a main road to where one or two smaller roads connect. The pleintje aims to improve this situation, by giving right of way to the main road, allowing them to pass the intersection without any delays. Apart from a reduced travel time on the main route, some side effects are less decelerating and accelerating from these same vehicles travelling on the main road. Which means a reduction in emissions and noise. Unlike roundabouts and priority intersections, no outdoor measurements have been performed to check if these possible advantages are indeed the case.

2.1.4 Crossability
The priority given to the main road, also has some other effects. Where vehicles on the main route can pass the intersection without any delays, traffic from the side streets have to give priority. Although, the reasoning is that these traffic volumes are lower compared to the traffic volume on the main road, so there are only a few cars affected by this. Also, traffic coming from the side streets on roundabouts and priority intersections, also have to stop and give right of way to those travelling on either the roundabout, or the main road of the priority intersection.

A bigger difference is the crossability for vulnerable road users like cyclists and pedestrians. Unlike the roundabout, the choice is made to not give the vulnerable road users priority when crossing the main road. This means that vulnerable road users have to rely on gaps in the traffic flow of the main road. With increased traffic volumes on the main road, the available gaps decrease and waiting times become longer. This may eventually lead to vulnerable road users accepting smaller gaps and cause dangerous situations.

One way to improve crossability is the addition of a median island between the two lanes of the main road. This makes it possible to cross the main road in two stages, one lane at a time. It therefore requires a smaller gap compared to the situation where two lanes have to be crossed at once. However, this is option is also used with roundabouts and priority intersections.

As can be read in the previous paragraphs, there are still quite a few unknowns around the functioning of the pleintje, especially when it is compared to the knowledge about the roundabout and priority intersection. It has some possible advantages and disadvantages compared to roundabouts and priority intersections, some of which are supported by the first evaluations of the pleintjes. In general though, the little practical research and experience with pleintjes, still remain a bottleneck to make any definite conclusions. Additional research could provide this insight and fill in some of the knowledge gaps that still exist.

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2.2 Problem description

Based on the previous paragraph, it can be concluded that there still is quite some discussion around the pleintjes. Proponents and opponents are still debating if the pleintje should be implemented and in which situations. One of the main reasons so much discussion about the advantages and disadvantages is still taking place, is because of the general lack of practical experience. Something that will hopefully be dealt with in the near future, as more of them are being build and evaluated.

The main thing those evaluations focus on, is how the pleintjes perform. In essence, this will also give more insight on the pleintjes itself, but from a research point of view it lacks a comparison with other types of intersections. When comparing different intersection types, it makes it possible to determine which intersections performs best under which circumstance and in what category (traffic flow, safety, etc).

Two students from the Windesheim College have performed a first comparison study between the pleintje, priority intersections and roundabouts\textsuperscript{10}. They managed to answer some of the first questions of the pleintje, comparing it to the roundabout and priority intersection. Their report will more or less be used as a starting point for this study. This research will also compare the above mentioned intersection types with each other, but will go more into depth on a few key issues.

As described in the previous paragraph, there are still a number of questions that are unanswered or could do with some extra research. From talks with different experts in this field, as well as involved parties, it has come to attention that one of the most important issues appears to be the safety of vulnerable road users. This research will mainly focus on this point and tries to give an answer how the safety of the pleintje compares to that of the roundabout and priority intersection. In special the conflicts involving slow traffic crossing the street. However, only comparing on traffic safety may give a skewed picture of the differences between the intersections. Next to safety, other aspects like traffic flow and emissions are also taken into consideration for the comparison. This way, a comparison between the pleintje, priority intersection and roundabout can be performed, based on a number of different criteria.

The next paragraphs will further define the chosen research path. They will formulate the problem definition, the research objective and the research questions for this study. How this study tends to find the answers to these questions, will be described and explained in chapter four.

2.3 Problem definition

The pleintje still has a few question marks hovering around it. This study will focus on answering some of them in order to get a better understanding how they work in practice and how this compares to more traditional intersection types as the roundabout and priority intersection. Therefore, the problem definition of this research is:

There are still knowledge gaps about the functioning of the pleintje in practice, in special related to traffic safety and the safety of vulnerable road users crossing the main road. As well as how does this rank compared to other intersection types like the priority intersection and the roundabout.

2.4 Research objective

With the problem definition known, the research objective and questions can also be defined. The research objective based on the problem definition is the following:

How does the pleintje, a priority intersection and a roundabout compare with each other, based on parameters like traffic safety, traffic flow and environment?

2.5 Research questions

In order achieve the set objective, a number of research questions have been proposed, which need to be answered at the end of this study. These questions are divided into one main question as well as several sub questions.

2.5.1 Main research question

The main research question for this study is the following:

How does the traffic safety of the pleintje, priority intersection and roundabout compare with each other?
2.5.2 Sub research questions

The sub research questions for this study are the following:

- Which conflicts appear on the pleintje, the priority intersection and the roundabout, between motorized traffic and cyclists?

- How often do these conflicts appear and how critical are they?

- What is the speed profile from the pleintje, the priority intersection and the roundabout? Of special interest is the place where the actual conflicts are happening.

- What are the speed dynamics of the pleintje, the priority intersection and the roundabout? And what does this mean for the traffic flow and environment?

- Are there other specific aspects (intersection design, etc.) that influence the traffic parameters and in what way?

Final words for chapter two

Looking back at this chapter, it has highlighted some of the problems that are the reason for this study. Based on this problem definition a research objective was formulated as well as the corresponding sub and main research questions. Before this study shows how these answers are going to be answered, some background information based on a literature study will be given to provide a solid basis for the rest of this study. The next chapter consists of this theoretical background and literature review.
Chapter three consists of the theoretical background and literature review relevant to the study. The main topics will address the principles of Largas, the different intersection types, collisions, conflicts and conflict analysis.

3.1 Background on the Largas principle

The first paragraph will address the Largas principle and the pleintje that has been developed based on these principles.

3.1.1 The Largas principle

The principle of Largas (a Dutch abbreviation for Langzaam Rijden Gaat Sneller, meaning slow driving goes faster), has first been introduced in the nineties. At that time, it was developed as an alternative method to road design, mainly in order to reduce emissions. As the environment was receiving more and more attention, as well as bigger problems like global warming and CO₂ emissions, plans were subsidized by the government in order to reduce emissions. One of these plans, was the Largas principle in order to reduce emissions caused by traffic. The main reasoning for this principle was to deal with the constant ‘running and stopping’ which is typical for most city roads, mainly caused by traffic lights. Instead, a more continues traffic flow would be tried to achieve because of the new design, as well as the introduction of the technology of an in-car speed limiter. This would force cars to drive at one continues speed, hence reducing emissions. Because of the link to this technology, it was initially put back on the shelf until it resurfaced a few years later¹¹. This time, it was stripped of the link with the speed limiter technology. It now was a new way to design road infrastructure with the possible advantages of improving traffic flow, road safety and a reduction of emissions and noise.

The way this method works is via new design for the road and the intersections. It is mainly used on roads which have a clear main flow and limited flows going in and out towards the side streets. This main flow takes priority on intersections, so the majority of traffic can quickly travel to their destination. The roads itself are also designed with a smaller profile to naturally force traffic to slow down to around 40 km/h. Some drivers are more easily influenced and will drive slower than others. As the design does not allow for overtaking (due to a barrier between opposite driving lanes for example), a 'train' of vehicles will appear at the rear of the slowest driving vehicles. Between these 'trains', gaps should appear. These gaps can be used by vulnerable road users (cyclists and pedestrians) to cross the main road, or by traffic from the side streets (access roads) to enter or cross the main road (distributor road).

As mentioned before, the aimed advantages of this design are to improve traffic flow and safety, as well as reduce emissions and noise. The traffic flow is improved, as the main flow is given right of way and doesn't have to stop at the intersections. This avoids any travel times losses which may be encountered at a roundabout or a signalized intersection. The absence of these stops also reduces emissions, as a lot of energy is wasted during braking and accelerating. The same goes for the reduction of noise. Especially braking trucks cause a lot of noise. Instead, traffic can now continue driving and should not need to stop anymore as long as they continue on the main road. Traffic safety could be improved by giving vulnerable road users the ability to cross the road in two stages, thus only needing to cross one lane at a time.

Of course, this is all mainly in theory\textsuperscript{12,13}. Only a handful of pleintjes have been build until now, so there isn't a lot of practical experience yet, neither are there many evaluations available for review. However, first reports do show positive signs. Travel times are reduced and the general traffic flow seems to do well. Also vulnerable road users and traffic from the side streets are able to cross and/or merge with the main road quite well. No reports on the effects on emissions and noise are available yet.

3.1.2 The pleintje
Along with the introduction of the Largas principle, a new intersection was also designed to be implemented along side. This would provide a complete design, both for intersections as well as for the road sections between them.

Figure 3.1: Example of a pleintje.

The new type of intersection which is introduced, is the pleintje (Figure 3.1). One of the key elements of the pleintje is the centre island. This centre island is designed in a way to create space for traffic willing to turn left. The way this is done, is similar to that of the roundabout, where traffic drives anti clockwise around a centre island. This design reduces the amount of conflict points compared to a regular priority intersection, potentially increasing its safety. A roundabout on the other hand has even less conflict points compared to the pleintje and can be considered being even safer.

The design also allows the main traffic to freely travel past the intersection as it has right of way (green line). They are not held up by traffic entering or leaving the road (orange lines). There are also no traffic light or obstacles (like with a roundabout for example) that slow them down. Instead, the road design should naturally slow the traffic down to a safe speed at the intersection. This speed reduction can be achieved by a small curve in the road for example. Vulnerable road users can cross the main road in two stages, as there is some space between both traffic lanes (red line). They can cross the first lane, than wait in the centre as a gap in the traffic of the other lane appears before they cross it. It has to be noted though, vulnerable road users crossing the main road does not have priority, like many roundabouts do provide to cyclists. Although some studies show this actually improves the safety of cyclists crossing\(^{14}\), it will make crossing the road more difficult, especially when the traffic volumes on the main road will increase.

The pleintje was originally indented as the intersection solution to be applied with the Largas design principle, completely converting roads into a Largas road. However, the pleintjes design has also been separated from the Largas principle and implemented as a stand alone solution for intersections that had a problem. This means that the pleintje is becoming another option when traffic managers are looking at possibilities for an intersection. Next to the standard intersections, like the roundabout, the pleintje is now entering the scene and establishing itself as proper alternative without the need to completely overhaul the roads leading to it.

### 3.2 Background of the other intersection types

Next to the pleintje, the priority intersection and roundabout are the two other intersection types which will be addressed in this study. Therefore, the next paragraph will give some background about the priority intersection and roundabout.

#### 3.2.1 Priority intersections

The priority intersection is one of the most traditional types of intersection used in the Netherlands. The basic design consists of one main road (distributor road), which has right of way over the intersection. Next to that, there are one or more side streets (access roads) connecting to the main road at the intersection. Traffic approaching the intersection from the side street has to give priority to traffic driving on the main road. This is a clear difference to other unsignalized intersections where priority is usually given to traffic approaching from the right. This also means, that this involves more rules, signs and markings around the intersection to make it clear to the traffic passing the intersection, informing them who has priority. Figure 3.2 shows one example of a priority intersection.

![Figure 3.2: Example of a priority intersection.](image)
Priority intersections further have many different forms throughout the road network. Some have a median island where left turning traffic can wait for a gap to appear in the traffic flow they are crossing. Other intersection do not have this, which means any left turning traffic has to wait on the main road, blocking any traffic coming from behind. Also, several ways to improve the safety have been implemented. Examples are elevated platforms, speed bumps, curves in the driving lanes, etc. Next to that, there are several ways to deal with vulnerable road users. Some priority intersections allow vulnerable road users to cross the main road in two stages, via a median island, where others force them to cross both lanes in one go. The same goes for the application of separated bike lanes or not. Most of these choices, median island, speed measures, bike lanes, etc, are based on the local circumstances like traffic volumes. This does mean however, that there is a wide range of different priority intersections available.

3.2.2 Roundabouts
A newer form of intersections is the roundabout. Even though the first 'roundabout' has been introduced roughly a century ago, the modern roundabout as we know today has only been implemented in the last few decades. Since the nineties, the amount of roundabouts in the traffic network has seen a significant increase and today there are roughly 4000 roundabouts in the Netherlands alone (all types). Next to the normal single lane roundabout, other types have been developed over time. However, this study will only focus on the single lane roundabout. An example is shown in Figure 3.3.

Figure 3.3: Example of a roundabout.

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The ‘modern roundabout’ is a circular junction where road traffic travels in one direction around a central island. Priority is given to the traffic driving on the roundabout, where all traffic approaching the roundabout has to give priority to those driving on the roundabout. This goes for all roads connecting to the roundabout, essentially making all branches equal regardless of road type or traffic volumes. The centre island cannot be driven over, so traffic is physically forced to drive around it. This deflection forces traffic to slow down and therefore pass the intersection at a reduced speed. This forced reduction of speed is one of the main contributors to the improved traffic safety caused by the roundabout. Next to that, the design of the roundabout greatly reduces the amount of possible conflicts between cars\textsuperscript{16}.

Another key element for roundabouts, at least in the Netherlands, is the way vulnerable road users are handled. When possible, roundabouts within city limits should be designed with separated bicycle lanes, as well as give priority to the cyclists. This means that all traffic approaching and leaving the roundabout has to give priority to any cyclists that may cross their path. The same goes for pedestrians, which are often also given right of way via pedestrian crossings. Even though this makes crossing these intersections a lot easier for vulnerable road users, it is questionable if this also improves their safety. Some studies show it is safer to take slow traffic, or at least the cyclists, out of priority, giving back right of way to the motorized traffic.

In general however, the roundabout has been a great success with regards to both traffic flow, as well as traffic safety. Numerous intersections have been redesigned as a roundabout, greatly reducing the number of crashes on the given intersections. Two main issues remain at this time however. The first is the above mentioned discussion about the priority rules for cyclists. The second is the effect of multiple roundabouts on a network scale. Stringing together a number of roundabouts is currently considered a safe solution, as traffic is slowed down at each intersection. However, this does reduce traffic flow on the other hand, simply because traffic is slowed down at each intersection and possibly have to give priority to crossing traffic. It is still up for debate if the advantages outweigh the disadvantages.

\textbf{3.2.3 Other intersection types}

This study focuses only on the pleintje, priority intersection and roundabout intersection types. This doesn’t mean there aren’t other types which can be used in the case of an access road connecting to a distributor road. The main absent intersection type is the signalized intersection. In this study, the choice has been made not to include this type, as the observed conflicts are completely different than the three types studied. In fact, due to the traffic lights crossing cyclists and passing cars should not be able to have a conflict at all. Hence, making the study to these conflicts impossible at a signalized intersection.

Other intersection types, like a raised plateau (access road vs. access road) or elevated crossing (through road vs. through road), are less relevant for this study as well.

3.3 Background on Sustainable Safe

The following paragraph will address the topic of sustainable safe and what this means for this study.

3.3.1 Sustainable Safe
Sustainable Safe was first introduced to further reduce crashes in Dutch traffic. It is a concept that aims to reduce the risk of a crash. If this is not possible, it aims to reduce the risk of severe injury as much as possible. The vision of Sustainable Safe itself is based on five principles

<table>
<thead>
<tr>
<th>Principle</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functionality</td>
<td>Mono functionality of roads as either through roads, distributor roads or access roads in a hierarchically structured road network.</td>
</tr>
<tr>
<td>Homogeneity</td>
<td>Equality of speed, direction and mass at moderate and high speeds.</td>
</tr>
<tr>
<td>Predictability</td>
<td>Road environment and road user behaviour that support road user expectations through consistency and continuity of road design.</td>
</tr>
<tr>
<td>Forgivingness</td>
<td>Injury limitation through a forgiving road environment and anticipation of road user behaviour.</td>
</tr>
<tr>
<td>State awareness</td>
<td>Ability to assess one’s capacity to handle the driving task.</td>
</tr>
</tbody>
</table>

Central in these principles is the driver. Not only is the driver the most vulnerable part in traffic, but it also the driver that makes mistakes or simply ignores the rules causing dangerous situation and possible crashes. Sustainable safe aims to reduce complexity in traffic (functionality, predictability), making it easier to drive, thus reducing the risk at a crash. On the other hand it reduces the risk of severe injury (homogeneity, forgivingness).

These principles have been put into practice. Not just changing infrastructure, but also via education, enforcement and vehicle technology. Although changes in infrastructure are usually the easiest to achieve progress with, it is the combination of these factors that should contribute to a more sustainable safe road network in the Netherlands.

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3.3.2 What does it mean for this study

So where does this theory of Sustainable Safe fit in with this study? As this study does not focus on checking if a pleintje fits with Sustainable Safe, as this has been done in the past already\(^\text{18}\).

So how does it fit in? In multiple ways actually. First off all, functionality is used to limit the scope of this study to certain types of roads. With the functionality principle, each road is categorized into a certain type of road, for example distributor road. This study focuses on intersections where a distributor road connects with an access road, which are based on the Sustainable Safe road categorization.

Second, homogeneity is another principle which is linked in this study. As for the traffic safety component, conflicts between crossing cyclists and passing vehicles. Actually quite the opposite of a homogenous traffic as these crossing streams have different speeds, driving directions and mass\(^\text{19}\).

Third, the basic aim of Sustainable Safe is to minimize both crash risk and injury risk. This study also focuses the Traffic Safety aspect on these risk, where conflicts are used for the crash risk and speed for the effects or injury risk.

3.4 Theory on crashes, conflicts and analysis

The next paragraph will address the topics regarding crashes, conflicts, as well as the analysis of both.

3.4.1 Crashes and analysis

One of the best indicators for traffic safety is a crash analysis of a certain road or intersection. In order to make an analysis, several crash databases are available. Examples of these database are the BRON database as well as the LMR database. The first is filled with information from the police, when they respond to a crash. The second is based on registered cases in hospitals. Next to those, also the CBS (Dutch bureau for statistics) provides certain information sheets on traffic crashes.

The most commonly used database is the BRON database. Mainly because this used to be the most accurate and extensive database as the police took notes of many details involving the crashes. Based on this database, crashes can be sorted on type (car vs. car, bike vs. car, etc), location (road, intersection), and many other parameters. Next to that, the result of the crash is also taken into account. These can be divided into ‘only material damage’, ‘minor injury’, ‘serious injury/hospitalized’ and ‘deadly injury’. In general, this database would give a good view of the traffic safety of certain intersections, like the roundabout, as it can be easily looked up in the database.


However, in recent years, the registration rate of crashes have dropped significantly. This means that not all crashes are registered anymore, or not with all details which have been provided previously. This makes it increasingly more difficult to use this crash data for analysis. On top of that, the pleintjes have only been built in those recent years, meaning that there is hardly any usable data to perform an crash data analysis for the pleintjes. Not only due to the fact that the registration rate has dropped, but also that it is rather hard to say anything about the general traffic safety based on the figures of only two or three years. It would be preferred to have a dataset over a longer period of time to avoid any irregularities or other deviations which may greatly influence a smaller dataset.

Crash data is not completely useless for this study. Even though it can't be used to say something significant about the traffic safety of the pleintjes in general, it can be used to see certain patterns in traffic safety in general. When looking at the total number of traffic fatalities, it can be seen that there is a downwards trend in general. The same can be said for most individual road users, like cars, cyclists and pedestrians. Traffic fatalities amongst cyclists however, are not reduced as much as other traffic participants.

Looking closer at the cyclist traffic group, it can be seen that the majority of the traffic deaths amongst cyclists are due to a crash where a cyclist and a motorized vehicle collide. Next to that, it can be noted that the majority of these crashes take place within city limits, as well as on intersections. The most common type of crash between a car/van and a cyclist is the one where a cyclist crosses a road²⁰.

Apart from traffic casualties, there are similar statistics for serious and light injuries. These show the same figures as with traffic casualties, with the exception that the involvement of motorized traffic as the collision partner becomes lower. This is mainly due to the fact that with less severe crashes regarding cyclists, there is a larger group that consists of a unilateral crash. For example where a cyclists hits the sidewalk, falls and ends up with a minor injury.

In general though, as the aim of this study is being about traffic safety on intersections, a focus on crossing cyclists versus motorized traffic would be a good indicator based on this quick analysis of general crash data.

3.4.2 Conflicts
As can be seen in the previous paragraph, traffic crash analysis is usually the fastest way to make any statements about traffic safety. However, it was also pointed out that due to two reasons, lower registration rate and the lack of good data for the new pleintjes, crash data is hardly usable to make statements about the traffic safety regarding pleintjes.

Luckily, researchers have found an alternative for traffic crashes, traffic conflicts\(^{21}\). In fact, all crashes are the result of a conflict that took place. Conflicts are a common appearance in traffic. Anything from having to brake because your predecessor slows down for a traffic light, from a pedestrian crossing a street, forcing you to wait. They can all be considered as conflicts and there are many different types of conflicts.

Most conflicts are easily resolved, by having one or both parties involved taking an evasive manoeuvre. This could be braking, making a turn or even speed up to quickly pass before another approaching vehicle. However, a small number of conflicts is not solved by an evasive manoeuvre, thus ending up as a crash as two traffic participants collide.

But what do these conflicts mean for traffic safety? As mentioned, conflicts can be used as a substitute parameter for traffic crashes. Simply said, if there are a lot of conflicts between crossing cyclists and passing cars on one intersection, and there are hardly any of those conflicts on another intersection, it would be an indication that there is a higher chance of a car hitting a crossing cyclist on the first intersection, thus being unsafe compared to the other intersection.

Of course, this is a very simple generalization, as there are many other variables that influence the chance of a crash occurring, like speed, type of conflict or evasive manoeuvres taken. In order to take these variables into account and use conflicts as a substitute for crashes, conflict observation techniques have been developed.

3.4.3 Conflict observation
Even though there are many different observation techniques around the world, the one which will be discussed here, is the Dutch observation technique DOCTOR, specifically designed for the Dutch situation\(^ {22, 23}\). This methods makes use of trained observers which are placed near an intersection and simply observe traffic, in special any conflicts which may occur. For this method, a difference is made between general conflicts and so called 'critical' conflicts. A critical conflict is determined by either the TTC (Time to Collision) or the PET (Post Encroachment Time). The TTC value gives an indication how much time remains when two road user continue their current speed and course before they collide. The later either of the road users take an evasive manoeuvre (i.e. braking), the lower this TTC value will be. A TTC value lower than 1.5 seconds is considered to be a critical situation. Next to the TTC value, the PET value is used to determine if a conflict is critical or not. The PET value is the


time difference between two vehicles passing the same road area. As with the TTC, the lower the value, the serious the conflict. During the observations, it is rather difficult to exactly determine these values, but experienced observers can make a fairly accurate estimate of them, determining if a conflict is critical or not.

As soon as a conflict is marked as critical, a form will be filled in with other details of the conflict. These details include the type of conflict (car vs. car, bike vs. pedestrian, etc), driving directions, driving speed, any evasive manoeuvres taken and the estimated injury severity. Finally a grade is given to the conflict between one and five. One being a mild conflict and five being a very serious conflict.

Using this method, it gives a good overview of the type of conflicts and the severity of them. With this data, a comparison can be made between different situations (intersections) based on traffic safety. With the difference that it is conflict data which is used instead of traffic crash data.

3.4.4 Conflicts versus crashes

But what does this conflict observation method mean for this research. As mentioned earlier, conflicts are another parameter to determine traffic safety of a road or intersection, just like crash analysis. Since crash analysis isn't a real option for this study, the choice for conflict observation was made. However, there is no clear relation between conflicts and crashes. Even though other researchers have tried, no direct relation has been found yet. One can understand that the higher the number of conflicts observed, the bigger the chance a crash will happen. But there is no formula which states that under X circumstances, Y number of conflicts will result in Z number of crashes.

What does this mean for this study? For a first general comparison it doesn't matter much as long as the data used for the intersections are either all from a crash analysis or all from a conflict observation. That way the compared data is the same for each intersection. As in a comparison it doesn't matter if crashes or conflicts are used. If either one is higher for a certain type of intersection, it means it is most likely less safe compared to another type of intersection which has a lower number of crashes or conflicts.

However, this covers just part of the comparison. As the second part consists of a monetary comparison where each parameter is expressed in money. This does bring forth a problem with regard to the traffic safety parameter. When using crash analysis the number of crashes, be it deaths, serious or light injuries can just be multiplied by their statistical monetary values. As a traffic death has a certain statistical value and the same goes for injuries. For conflicts on the other hand, this is not possible, as there is no monetary value that goes with conflicts. Since a conflict is only a conflict and not a real crash, there are no deaths and injuries.

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This study has an advantage though. It only focuses on a small number of intersections, which makes the results rather location specific. This means that for each location a relation between crashes and conflicts can be found meaning the observed number of conflicts can be converted into crash data, thus expressed in a monetary value. This is done by looking at the crash data and note the number and type of crashes which relate to the observed conflicts. In this case, cars crashing with a cyclist. The result of this comparison means that an $X$ amount of conflicts over a certain time relate to an $Y$ amount of crashes over a certain time, giving a relation between the two.

For example, there are eight measured conflicts during the measurement day. For the same intersection, crash data gives three crashes over a ten year period. In ten years, the measured number of conflicts would be $365 \times 10$ higher, resulting in 29,200 conflicts. Which would relate one crash to 9,733 conflicts. Or the other way around, each conflict has a 0.0001 chance of becoming a crash. This way, the number of measured conflicts could be transferred into crashes, making it possible to attach a monetary value to them based on the death and injury values.

**Final words for chapter three**

The past chapter has given a deeper insight into the different topics relevant for the rest of this study. Not only has it provided background information on the three different intersection types which are central in this study, it has also given information about crash analysis, conflicts and conflict observation. This is of importance as a big part of the traffic safety aspect for this study is based on conflicts and conflict observation. Last but not least, it has given some background about Sustainable Safe and how this is relevant for this study.

With this information known to the reader, it is time to focus on the study itself. Before any question can be answered though, a plan of action should be put in place. What data is needed to answer the questions and how will this be obtained? The next chapter will deal with these aspects.
This chapter will give an overview of the different research methods available for this study, as well as the reason why a certain research method will be used. Chapter two described ‘what’ will be studied, while this chapter will aim to answer the ‘how’ question. The first part will give an overview of the different methods and the preferred method. Part two of this chapter will show how the chosen methods will be used in practice. The third part will give an overview about different comparison methods, as well as the parameters that are needed for the preferred method.

4.1 Description of the different methods

This first paragraph will address the different methods available, as well as the preferred method. It consists of methods regarding conflict observation, speed measurements and finally the simulation tool.

4.1.1 Conflict observations

One of the key areas of the study concerns traffic safety. Traffic safety research is usually performed based on actual traffic data. Or crash data to be more specific. As previously described, there are a few large databases available for this type of research. However, it also mentioned a few critical problems with this method. The registration rate and the quality of the data has significantly dropped in recent years. Combine this with the fact that pleintjes only exist for a few years and one can understand why crash data is not a good way to determine traffic safety at a pleintje. Therefore, the suggestion was made to use an alternative in the form of conflict observation.
Conflict observation is a method used to spot conflicts in traffic and use those to determine an alternative parameter in order to characterize traffic safety of the observed road or intersection. The specifics about this observation method can be read in the previous chapter, but in general it has a few advantages for this study. The most important one being the time factor. Conflict observations only require a limited amount of time in order to provide enough data to draw a conclusion about the traffic safety. This is obviously related to the amount of conflicts appearing at a certain intersection. But with the right locations, it should be possible to get results quickly. A pre observation at the proposed locations should give a good indication if there will be enough conflicts to observe or not. When the right locations have been chosen, it should be possible that all types of intersections can be observed in a relatively short time span. Since all observations would give the same type of data, it can also be easily compared. The limited time required as well as the comparability of the data, makes the conflict observation method a good alternative for this study in order to make statements about the traffic safety of the different intersections.

The data which will be collected during the actual observation will be a list of witnessed encounters, conflicts and critical conflicts, as well as their characteristics like driving direction, evasive manoeuvres, priority rules, etc. It is good to define what will be seen as an encounter, a conflict and a critical conflict though, mainly for future reference in this study.

The first group is the largest and contains all encounters witnessed at the specific intersection. In this case, an encounter is defined as any meeting between a crossing cyclist and a passing car, where they would want to occupy the same area at the same time. The dataset of encounters also includes all conflicts and critical conflicts. The second group is the group of conflicts. A conflict is essentially the same as an encounter. However, a normal encounter is solved in a normal way by having either the car or cyclist give right of way to the other according the priority rules. With a conflict, a serious evasive manoeuvre has to be made in order to prevent a collision from occurring. For example, a car braking for a cyclist, while the car has priority. The third and last group are the critical conflicts. They are an even smaller group out the conflict group. They have the same characteristics with another difference. The observed Time to Collision (TTC) is estimated to be under 1.5 seconds, meaning a collision was barely avoided.

So basically there is a big group of encounters which include all observed encounters between a crossing cyclist and a passing car. A smaller portion of this group are the conflicts, which are more serious in nature. An even smaller portion from this second group are considered the critical conflicts, where a crash was only just avoided. All of this is rather subjective, as the observer has to make personal observations and estimates to type of encounter, conflict or critical conflict. Therefore, both conflicts and critical conflicts have been reviewed by another observer as well.
For the actual observing of the different intersections, there are two main ways to collect the data. A manual method and a method involving cameras. The first method, the manual method, is commonly known in the Netherlands as the DOCTOR observation technique. With this method, one or more trained observers take place at an intersection and simply observe the conflicts as they happen in front of them. For each conflict, a pre-designed sheet is filled in, describing the characteristics of the witnessed conflict. In the end, the information noted on the sheets can be used to determine the parameters for the traffic safety.

The second method is the use of cameras. In this case, cameras are placed at the intersections and record the traffic situation. After observations have been finished, the recorded material has to be analyzed for the possible traffic conflicts. This analysis will eventually result in the same traffic safety parameters as with the manual method.

There are obviously advantages and disadvantages to both methods. The manual method is harder to execute, as it would require trained observers who are able to collect all the data about a conflict in a short time span. When using camera footage, the film can be paused and replayed, so all the data can be easier reviewed, even by (slower) less trained observers. On the other hand, the time needed to review the camera footage will be longer compared to the manual method, even when forwarding between conflicts. One last advantage of the camera method is the fact that it is possible to gather more information from the same footage, for example speed and traffic volumes. With the manual method, it would require another observer to collect this additional data.
4.1.2 Speed measurements
Apart from the conflicts occurring, another important aspect of traffic safety is speed. After all, the higher the speed becomes, the bigger the chance at serious injuries or even fatalities during a crash. Therefore, measuring speed at the different intersections will give some more information about their safety. Interesting speeds to know would be the approach speed before the intersection, their possible deceleration and the actual speed in the conflict zone. These speeds can be measured and formulated as averages or the v85 for example. For each intersection these speeds can be determined and eventually compared with each other.

In order to gain the speed data of the intersections there are a few different methods available in order to acquire this data. The first would be measuring the speed using a laser gun or something similar. This will provide quick and accurate data of the speeds. A second method would be to observe the intersection and estimate the speeds. For example, based on the time it takes to pass two fixed points. This method would be quicker than the first, but the data collected will be less accurate due to them being estimates. A third method would be the use of cameras. Record the traffic situation and analyze the speed afterwards, using the same fixed point method mentioned before.

Time wise, all methods will roughly take the same amount of time. As all methods require to observe traffic one way or another and directly measure the speed based on the observations (either in real time, or afterwards on film). The main difference will be the accuracy. Using the laser gun would most likely give the most accurate data, while the other two result in (slightly) less accurate estimates. One advantage of the last method, is again the option to use the same camera footage for multiple types of data.

Based on the available methods, as well as their advantages and disadvantages, a choice has been made to which data collection method will be used. In the end, the camera method will be the preferred method for both the conflict observations and the speed measurements. These camera images can also be used to observe traffic behaviour, ambient influences as well as determine traffic volumes.

The main reason for choosing the camera method is the simple fact that the acquired data can be used to cover most of the preferred measurements as well as collecting it within a short time frame. All the necessary data can be collected in one go and then be analyzed afterwards at another time. More importantly, it can be analyzed by a single (untrained) person watching the camera footage and it doesn't need any trained observers to be observing the intersections.
4.1.3 Simulations

Aside from the camera observations, which will mainly yield parameters about traffic safety, another source of data collection is needed for parameters about traffic flow and environment. In order to collect data about these parameters there are a few options available. First off all, measuring emissions and travel/waiting times at the intersections themselves. The latter could also be gathered from the video images. A second method would be to make an estimate based on the decelerating and accelerating of the cars at intersection. The larger the speed dynamics of the cars, the worse the emission get and the longer the travel times will be. The third option would be the use of a simulation tool that simulates the traffic and calculates the parameters based on this simulation.

While each method has its pros and cons, the final decision was made to use a simulation tool. The second method of the speed dynamics would only give a global indication of the emission and traffic flow parameters, which make it less usual for an actual quantitative comparison between the intersections. Which leaves the outdoor measurements versus the simulation tool. Even though both options would result in accurate data, the choice was made to use the simulation tool instead of outdoor measurements. The main reason for this is due to time constraints. Using outdoor measurements takes up quite a lot of time again, taking the measurements at the six intersections again. Next, all the collected data has to be processed and analyzed as well. While on the other hand, using simulations, all this data can be collected in an afternoon. As a lot of time went into the traffic safety parameters linked to the conflict observation and speed measurements, no time was available to also perform outdoor measurements for the traffic flow and environment data. Hence, the final decision to make use of a simulation model instead and collect the data that way.

The choice for a simulation model does lead to another choice. The question to which simulation model should be used to get the data needed, as there are many different simulation models, each with their own usefulness. The CROW institute in the Netherlands however, has written a publication about Largas, as well as developed a simulation tool to go with it. This tool is designed to compare pleintjes with other intersection types like a roundabout or a priority intersection, which is exactly what would be needed for this study.

So what does this Largas simulation tool actually do? The tool is basically a micro simulation model which simulates individual vehicles and bicycles driving over a predefined intersection or network of intersections. As a user, one enters a number of different parameters into the program, like traffic flows, type of intersection, driving behaviour, etc. Based on these parameters, the program will run the simulation. During the simulation, the network, cars and cyclists are visualized. After the simulation has finished, an output file will be published containing the simulation results. These results contain information about waiting times for cars, cyclists and pedestrians, emission values like NOx and PM10, fuel usage, average driving speed, etc.
For this study, only a number of simulation parameters have to be inserted. These consist of the traffic volumes for cars, trucks and cyclists. Furthermore the type of intersection and the dimensions of the intersection. Note, it is possible to simulate up to five intersections in a small network, but for this study only single intersections have been simulated. Other parameters like driver behaviour have been left at their default values and are equal for all simulated intersections. From the output file, there are numerous results available. However, for this study, the ones that are of interest are the (average) waiting times for cars and cyclists. These values will be used to determine the traffic flow parameters, as they address the time losses at the intersection. Other important values are the number of stops from cars and the CO\textsubscript{2} and PM\textsubscript{10} emission values that are derived from these stops. These values will be used to cover the emission side of the comparison.

As good as it may sound, a simulation model remains just that, a simulation. Even though current models are getting rather close to simulating a 'real' traffic situation, they still are just an approach of reality. This simulation tool is no different. Even though there are numerous parameters to tune the model and create realistic traffic conditions, there are still a few flaws in the program. For example, the program sometimes ends up in a gridlock, meaning traffic is stuck as one lane blocks the other and vice versa. In reality, such a problem could occur too, but would be solved by the road users eventually. The program however, is not able to do this.

Another aspect is the behaviour of road users. Unlike in the real world, the simulated road users will always obey the traffic rules. In reality, some cyclists would use the road area to cross an intersection, or cars taking a shortcut on a roundabout during quiet times. These kind of incidents will not be simulated.

Last but not least, the traffic behaviour of cyclists in general. What is meant with this, is the simple fact that all simulated cyclists will drive on the right side of the road, as well as pass each intersection anti clockwise. In reality however, cyclists quite often cycle against traffic and just take the quickest route over an intersection. In the simulation, this is not the case.

However, taking the simulation limitations into account, the model is still the best option in order to get the required data about the environment and traffic flow. Therefore, the Largas simulation tool will be used to gather the values regarding emissions and traffic flow.
4.2 Application of the different methods

While the previous paragraph described the available methods, as well as the preferred one, this paragraph will describe how these methods will be put to work.

4.2.1 Locations

In order to compare different intersections, data from each type of intersection is required. Therefore, observations from all three types are needed. In order to conclude something reliable out of the data, multiple intersections of each type need to be observed. However, a balance between the time needed and available on one hand and the preferred amount of observations on the other, needs to be found. This decision has been made easier by the actual availability of the measurement truck, as it appeared there were only six days available, where the truck was available for measuring. This led to the result that each type of intersection will be observed twice. Two pleintjes, two roundabout and two priority intersections. This does mean this study can only give a first indication as to how these intersections rank to each other. No general conclusions can be made as the number of intersection reviewed is too small. However, it still gives a good opportunity to test the chosen methods and see if they work as intended, or if they need to be changed with further research.

The actual locations would need to meet certain criteria. First off all, the intersection would need to have sufficient traffic volumes, in order to be able to extract enough conflict and speed data from the camera footages. Second, there should be space available where the measurements truck can be parked and set-up. This would be a place near the intersection, in order to get a good overview. Third, all intersections should show similar traffic conditions and are preferably in the same municipality for the same reasons (traffic behaviour differs from place to place). Fourth, the locations should be within a reasonable distance from the TU Delft, who provides the measurement truck.

Taking these criteria into account, two municipalities have been found which meet these criteria and were willing to cooperate. The two municipalities that have been chosen are Heerhugowaard and Purmerend. The last part of this paragraph will give an overview of the actual intersections. Note, larger maps of these intersections can be found in the appendices.
Pleintje Heerhugowaard

The pleintje in Heerhugowaard connects the Westtangent, a distributor road, with two access roads, namely the Umbriellaan and the Jupiterlaan. The intersection is situated within city limits and therefore the maximum speed is 50 km/h. The main road connects this intersection to a roundabout on one side, while on the other a controlled crossing for vulnerable road users is situated.

The design of the pleintje is rather large when compared to most others, resulting in a big slap of concrete and other pavement. The entire intersection has separated bicycle tracks, which have priority over the side streets, but have to give priority to the main road. The same goes for pedestrians.

The choice for a pleintje at this intersection makes sense, as there is a clear main flow over the Westtangent in both directions and limited traffic coming from and going to the side streets. A priority intersection could have also been constructed following this line of reasoning. But since the connecting roads are designed according to the Largas principle, it makes sense to also use the Largas intersection design at this location, thus implementing a pleintje. Figure 4.1 shows an image of the pleintje.

Figure 4.1: Pleintje in Heerhugowaard.
Roundabout Heerhugowaard

The roundabout in Heerhugowaard connects the Westtangent, a distributor road, with two access roads, namely the Deimoslaan and the Icaruslaan. The intersection is situated within city limits and the maximum speed is 50km/h. The main road connects this intersection to a pleintje on both sides, of which one is the pleintje described above. The other pleintje is of a similar design as the first.

The roundabout has a common design, being a single lane roundabout with separated bicycle tracks. Priority is given to both cyclists and pedestrian on all four branches of the roundabout.

Since there are two pleintjes adjacent to this roundabout, as well as the design of the Westtangent being Largas, it does raise the question why this intersection is not a pleintje too. There are probably two reasons for this. First off all, the traffic volumes. Compared to the pleintje, one of the side streets, has a significantly higher volume. Not as large as the traffic volume on the Westtangent, but definitely higher compared to the other side streets. This could have lead to problems when building a pleintje, as this would have resulted in traffic from this side street having to give priority to all traffic on the Westtangent, possibly forming quite a queue because of it. The second reason would be a large cyclist volume crossing the Westtangent at this intersection.

Since there are residential areas on one side and two secondary schools on the other, as well as several office buildings, it generates a lot of cycle traffic between the two. As all these cyclists would have to wait if the intersection would be a pleintje, the choice has been made to make a roundabout, where all cyclists can cross without any delays. The choice for the roundabout is therefore probably made from a cyclist perspective and not from a motorized traffic perspective. Figure 4.2 shows an image of the roundabout.

Figure 4.2: Roundabout in Heerhugowaard.
Priority intersection Heerhugowaard

The priority intersection in Heerhugowaard connects the Zuidtangent, a distributor road, with two access roads, namely the Bevelandseweg and the Stationsplein. The intersection is situated within city limits and the maximum speed is 50 km/h. The main road connects this intersection to a signalized intersection on one side and a railway crossing on the other.

The priority intersection has a slightly different design compared to the other two intersections. This is because one direction, the one leading from the railway crossing to the signalized intersection, has not one, but two continues lanes. The other direction has one continues lane, but does have a separate turning lane for traffic turning left. The reason this intersection has been chosen though is twofold. First off all, the traffic volumes are roughly the same compared to the other two intersections in Heerhugowaard. Second, it appeared to be difficult to find a priority intersection with complete separated bicycle tracks. This intersection does have this feature. As with the pleintje, the cyclists and pedestrians have priority over the side streets, but do have to give priority to traffic on the main road.

The choice for a priority intersection is probably made because of a few reasons. First off all, there is a clear main traffic flow over the Zuidtangent, while there is less traffic from the side streets. This makes a roundabout unneeded, as it would make all branches equal, even though they are quite clearly not. Next to that, this intersection does not have the large cyclist flows like the roundabout does have. Second, unlike the Westtangent, the Zuidtangent is not designed according to the Largas principle, therefore it makes less sense to build a pleintje and just build a priority intersection instead. Third and last, the adjacent railway crossing and the signalized intersection need plenty of buffer space for waiting vehicles. This also results in dual lanes at the intersection. Something which goes against the design philosophy of the pleintje, where single lanes are key. Taking this all into account, the most logical choice at this location would be the priority intersection. Figure 4.3 shows an image of the priority intersection.

Figure 4.3: Priority intersection in Heerhugowaard.
Pleintje Purmerend

The pleintje in Purmerend connects the Churchilllaan, a distributor road, with one access road, namely the Henry Dunantstraat. The intersection is situated within city limits and the maximum speed is 50 km/h. The main road connects this intersection to a zebra crossing, followed by a roundabout on one side and another pleintje on the other, followed by a railway crossing not much further.

The pleintje has a general design, although quite a bit smaller compared to others. Part of this is probably because of this intersection only having three branches. Next to this, the centre island is also slightly different compared to other pleintjes. Where on most pleintjes, the centre island completely separates the left turning movements, this centre island does not. There is still an elevated area in the centre, but both left turning movements can slightly conflict with each other. Last, but not least, this intersection also has separated bicycle tracks. Again giving priority to the main road and receiving priority when crossing the side street.

The choice for a pleintje at this location has again to do with the traffic volumes and the design of the road leading up to it. There is a clear main flow of traffic over the Churchilllaan. The traffic volume from the side street is larger compared to the pleintje in Heerhugowaard. However, space is a major issue when opting for a roundabout in this location. Not only because of existing buildings, but also the close proximity of another intersection. This would make it impossible to build two roundabouts that close to each other, resulting in either a pleintje or a priority intersection. Finally, this part of the Churchilllaan has been redesigned according to the Largas philosophy. So it makes sense to build a pleintje instead of a priority intersection to have it fit in with the rest of the roads design. Figure 4.4 shows an image of the pleintje.

![Figure 4.4: Pleintje in Purmerend.](image)
Roundabout Purmerend

The roundabout in Purmerend connects the Churchilllaan, a distributor road, with one access road, namely the Hannie Schaftstraat. The intersection is situated within city limits and the maximum speed is 50 km/h. The main road connects the intersection to a zebra crossing followed by a pleintje on one side and another roundabout on the other. The pleintje is the same pleintje mentioned above.

The roundabout has a common design, being a single lane roundabout with separated bicycle tracks. Priority is given to both cyclists and pedestrians on all three branches of the roundabout.

The choice for a roundabout on this location is a little less obvious as with the others. There is a clear main flow of traffic over the Churchilllaan, making a pleintje or priority intersection the preferred option. Next to that, the bicycle flows do not suggest a need for a roundabout either. The only high intensity for bicycle traffic is the stream crossing the side street, which usually also has priority with the other designs. The most logical explanation is probably the fact that this roundabout was built before pleintjes were developed, making it a choice between a roundabout and a priority intersection. The choice for a roundabout is probably made because it appeared to be a lot safer compared to priority intersections. Figure 4.5 shows an image of the roundabout.

Figure 4.5: Roundabout in Purmerend.
Priority intersection Purmerend.
The priority intersection in Purmerend connects the Burgemeester D. Kooimanweg, a distributor road, with one access road, namely the Professor Meester P.J. Oudlaan. The intersection is situated within city limits and the maximum speed is 50 km/h. The main road connects the intersection to several small residential area exits, before connecting to a roundabout. On the other side, it connects again to several small residential area exits, before connecting to another priority intersection.
The priority intersection has a regular design, with separated bicycle tracks all around. Priority is given to traffic on the main road, while priority is received when crossing the side street.
The choice for a priority intersection at this location makes sense. Traffic volumes are not that high, for both motorized traffic as well as cyclists. So with a clear main flow, little traffic to and from the side street, as well as little bicycle traffic, it makes no sense to construct a roundabout at this location, leaving the options open for a priority intersection or a pleintje. Since there is no Largas designed road connecting to the intersection there is little incentive to build a pleintje at this location, making a priority intersection the obvious choice. Figure 4.6 shows an image of the priority intersection.

Figure 4.6: Priority intersection in Purmerend.
4.2.2 The measurements
Apart from the locations, other important aspects are the number of observations per location as well as the time and date of the observations. Since performing the camera observation and more importantly the processing of all the data takes up a lot of time, a balance has to be found between the available time and the amount of observations. With this in mind, it has been decided to perform one full day of observations per intersection.

For the actual measurements, a measurement truck was available with all the needed equipment. The basic set-up consists of a trailer which has a large pole attached to it. At the top of the pole, two cameras are fitted, which are used to film the traffic at the intersections. The images from the cameras are directly recorded by hard disk recorders, from where the data can be reviewed later (or burned to DVD and then reviewed). Using two cameras made it possible to view the intersection from two (slightly) different angles, as well as focus the cameras on different points of the intersection.

The measurements took place during the day, as the cameras needed a fair amount of daylight in order to have any clear images. This restricted the starting time of the observation, which was generally between 7:30 and 8:00. Observations usually ran for 8 hours straight and finished around 15:30. This provided a large enough dataset for each intersection, as required for this study.

Even though preference was given to film the different intersection at the same day (to reduce daily differences in traffic volumes, etc), the limited availability of the measurement truck determined the actual observation schedule, which can be viewed in the next paragraph.

4.2.3 Measurement schedule
The following list is an overview of the measurement schedule which has been carried out.

- Wednesday 10 October, Pleintje Heerhugowaard.
- Thursday 11 October, Roundabout Heerhugowaard.
- Tuesday 23 October, Priority intersection Heerhugowaard.
- Thursday 25 October, Priority intersection Purmerend.
- Wednesday 31 October, Pleintje Purmerend.
- Wednesday 7 November, Roundabout Purmerend.
4.2.4 Simulation runs
As mentioned in paragraph 4.1.3, the decision was made to use a simulation program in order to obtain data about emissions and traffic flow. This does mean, there has to be made a choice for the different parameters needed in order to run the simulation itself. This paragraph will deal with the different parameters and the reason why those variables have been chosen.

The first parameters are the design and geometry of the intersections. The simulation model consists of a set of 10 predefined intersection types, including the priority intersection, roundabout and pleintje. After selecting the type of intersection, more details of the intersection can be specified. For example, distance between the bicycle lanes and the main road, width of the centre island, or the roundabout diameter. All the available values, as well as the choice for the intersection, are based on the real world situations which have also been observed with the cameras. All dimensions have been measured in order to recreate the same situation within the simulation tool.

The second set of parameters define the traffic flows over the given intersection. Different origin and destination matrices can be provided for cars, cyclists, trucks, Public Transportation and pedestrians. As with the geometry design parameters, the traffic flow parameters are also based on the real world counterparts. Based on the video images, traffic volumes, as well as origins and destinations have been determined. However, in order to get an equal comparison, all three intersections for a city have been simulated with the same traffic volume parameters. Both for Heerhugowaard and Purmerend, the intensity values of the roundabout will be used in the simulations.

Finally, there is a large set of other variables which can be adjusted in the program. These are divided into parameters about driver characteristics (speed preferences, gap acceptance, etc), car characteristics (size, weight, type of fuel, etc) and simulation characteristics (length of simulation etc). All of these parameters come with default values based on sources as the CBS (Dutch Bureau of Statistics) and the ASVV (Dutch Manual for Road Design). Since these parameters have not been determined in the real world situations, they have been left at their default values.
4.3 Application of comparison

After collecting and analyzing the data, it will be compared, since that is the goal of this study. This section will address the different methods available for comparison, as well as describe the criteria used for the actual comparison.

4.3.1 Comparison methods

In order to compare the three different intersections a comparison method has to be chosen. However, there are several different methods available in order to compare the intersections.

The first method available would be a SWOT analysis of the three intersection types. A SWOT analysis maps out the Strengths, Weaknesses, Opportunities and Threats each intersection has. Roughly said it will list the advantages and disadvantages of the different intersections. This way they can be compared on the pros and cons for each intersection. The big downside of this method is that there is no quantification of any of the Strengths, Weaknesses, Opportunities or Threats. This means it will remain more or less a global comparison, where personal preferences to certain (dis)advantages would make the choice for the ‘best’ intersection.

A second method is the scorecard method. The scorecard method lists a set of pre-defined criteria and gives each intersection a value for each criteria. These values could be simple ‘+’ and ‘-’ or a value between ‘1’ and ‘10’. This results in a ranking for each intersection for each criteria. However, no weight factors are given to each criteria, making them all equally important. It also gives a slightly biased picture, as there are no measured values used again. For example, if the priority intersection would be marked as the neutral variant, both a roundabout and the pleintje could score better for traffic safety, both being awarded with a ‘+’. This would implicate both a roundabout and a pleintje would score equally good at the criteria traffic safety, even though one could be far better than the other. This could be solved by giving more ‘+’, but it would still be flawed compared to an actual quantitative comparison.

The previous methods both give a good first analysis of the different intersections. However, they lack any deeper comparison based on actual numbers. Therefore, a more quantitative comparison method is preferred. One such method would be the Multi Criteria Analysis, or MCA in short. The MCA also lists a number of criteria which are used to compare the intersections. Unlike the scorecard method, each criteria is given a (different) weight factor. Next to that, each criteria is expressed in a (measured) value for each intersection. This means there will be a weighted value for each criteria for each intersection and a total equation with all criteria can be made. This way, a ranking can be made for the different intersections, giving a ‘best’ intersection based on the chosen criteria.
A final method would be a cost benefit analysis, or CBA in short. In this method, all advantages and disadvantages of the different intersections are being expressed in a monetary value. Advantages would give a positive value, while disadvantages give a negative value. In the end, all values will be accumulated and it will give a total cost or benefit for the specific intersection. Again, this would give a "best" intersection based on the best value given by the cost benefit analysis.

These last two comparison methods both have strong advantages over the first two, as they express their criteria into measured values. Therefore, the last two have a preference over the first two. Comparing the MCA with the CBA, the MCA would probably fit into this study the best. The reason for this is the fact that a CBA takes all pros and cons into the equations, while a MCA is based on a set number of predefined criteria. Given de data collected, there are only a set number of criteria available. The CBA would simply require additional data which is not available at this time. For example traffic safety information on other conflict types, noise levels, land usage, etc. Therefore, the decision is made to use a MCA to compare the three different intersections with each other.

With the choice for MCA, two questions remain though. Which criteria will be used and how will they be weighed in the MCA? The criteria question will be answered in the next paragraph. As for the weighing factors, the answer is as follows. The final comparison will be done in several steps. First, all criteria will be determined and compared individually. In this case, no weighing factors are needed yet, as each criteria is looked at individually. This changes when the final comparison is made based on all criteria. The first comparison will be done based on percentages and an equal treatment of all criteria. Simply meaning that each criteria has the same weight in the total score. The second comparison however, will give each criteria a certain weight factor, as all criteria will be expressed in a monetary value. This is done by using the Rijkswaterstaat CBA indicators. These indicators are used to give a monetary value to certain parameters like the cost of a kilogram of CO\textsubscript{2}, the value of time, the cost of a traffic death, etc. These values are based on extensive studies in the respective fields. This way, each criteria is given a certain weight, as based on these CBA indicators each criteria has a certain value and is weighed accordingly.

### 4.3.2 Comparison criteria

The previous paragraph showed the choice for a comparison method. The final decision was made in favour of the MCA. This means though, that there is a need for a number of criteria which will be used in the MCA. As mentioned in previous chapters, the main comparison areas will be traffic safety, environment and traffic flow. Next to that, it has been mentioned what data will be available and how this will be collected. The final question which remains is how this data is transferred into parameters which can be used in the comparison. This paragraph will describe the different parameters which will be used based on the collected data.
Before describing the chosen parameters, it is good to know why these criteria have been selected in the first place.

First off are the two traffic safety criteria. As mentioned in previous chapters, the best way to get information about the traffic safety is to use make use of crash data and make an analysis based on that data. However, it was also shown why this is not possible, thus not able to include crash data as a criteria for the MCA.

The data which is available are the number of conflicts that occur during the observations, as well as the speed measurements. Basically, these two criteria give some insight into the risk of a crash (number of conflicts) and the risk of injury (speed). This also has a good link to Sustainable Safe, as it aims to reduce the risk of a crash. And if a crash occurs, to reduce the chance at a serious injury. So using these two criteria would fit in well with this line of reasoning.

Second, the two emission criteria. There are a bunch of different criteria available which could be used, for example, the values of several emissions like CO$_2$, NO$_x$, SO$_x$, but also number of stops at the intersection, fuel usage, etc. However, two of them stand out, mainly because they are relevant topics in (political) discussions. These are the emission values for CO$_2$ and PM$_{10}$. CO$_2$ is current due to the global warming issues. A lot of energy is put into the reduction of CO$_2$ emissions, including cleaner cars and all. Perhaps, a certain intersection design could also contribute to this. The second is PM$_{10}$ (fijnstof in Dutch). Especially around large cities, much debate is going on about PM$_{10}$. Measures like a reduced maximum speed are introduced to reduce these emissions. Since this is an actual topic, as well as the fact that the intersections which are studied are situated within city boundaries, makes PM$_{10}$ a very relevant criteria to take along in the MCA.

Third and last, the traffic flow parameters. There are several ways to measure how well traffic flows over an intersection. For example the total travel time needed to pass the intersection, or the percentage of cars/bikes that has to stop at the intersection. However, it was decided to use the waiting times for cars and bikes as criteria for the traffic flow of an intersection. The reason for this is simple. Waiting times correspond to the time 'lost' passing the intersection. Lost in this case, means the extra time needed to pass the intersection compared to when one would pass the intersection without any interference. The extra time needed is for example caused because a cyclist has to wait with crossing until all cars have passed. The main advantage of using this criteria is that this time loss can easily be given an monetary value using the value of time from the CBA indicators.
Conflicts (Traffic safety)
Based on the conflict observation technique mentioned earlier, an indication is given on the number of conflicts, with the focus being on conflicts between cars and cyclists crossing the street. The collected data will result in a total overview of all encounters between cars and crossing cyclists. Most of these encounters are being handled in good order between the car and the cyclist and show no problem. Part of them though, did not go as planned and are therefore called a conflict. A conflict between a car and cyclist means that the encounter did not go as it should have. (for example, a cyclist taking priority, having a car break) Next to these 'normal' conflicts, there is an even smaller number of 'critical' conflicts. These critical conflicts are considered to be more severe where a crash has barely been avoided.

Since the decision if something is an encounter, a conflict or a critical conflict, is made by the observer watching the video, it was decided to request a second opinion. A trained observer from Goudappel Coffeng served as a second pair of eyes in order to determine if a (critical) conflict was indeed one.

But how does this translate into a parameter which can be used in the MCA? The number of critical conflicts can be used as a sort of 'crash risk' for each intersection. However, not all the traffic volumes are equal for each intersection. Therefore, the number of critical conflicts have to be rated against the traffic flows of both the cars and the cyclists. This would result in a parameter where the number of critical conflicts is rated against a certain traffic volume, where the traffic volume is equal for each intersection and thus easily comparable.
Speed (Traffic safety)
The second criteria for traffic safety is the measured speed. For each intersection, the speed has been determined based on the video material. Where the conflicts give an indication as to the risk of a crash, the speed is the main characteristic to the effects of a crash. As can be seen in the figure below, with increased impact speed, the risk of a fatal injury increases, as can be seen in Figure 4.7.

![Figure 4.7: Impact speed vs. Fatality risk.](image)

The measured speeds can therefore be translated into a risk factor for each intersection, which will be the parameter used in the MCA. Combined with the conflict parameter, both traffic safety parameters address the risk and effect of crashes between cars and crossing cyclists at the different intersections.

CO$_2$ and PM$_{10}$ emissions (Environment)
In the category environment, there are two criteria which will be used in the MCA. Both of these are emission values based on the results from the simulation. The two emission values that have been selected are CO$_2$ and PM$_{10}$. Both are based on the same car dynamics at the intersection, or the number of stops to be more specific. More stops means more braking and accelerating, meaning a higher emission load. However, both CO$_2$ and PM$_{10}$ have rather different meanings. CO$_2$ on one hand is the main factor when speaking about global problems. Carbon footprint, global warming, etc. So the amount of CO$_2$ emitted is a good indicator for the contribution of each intersection type on a global scale. PM$_{10}$ on the other hand is more a local parameter. Since all intersections which are taking into account are within city limits, a parameter addressing the local environment would be a sensible addition. PM$_{10}$ (fijnstof in Dutch) is a value for the amount of particle matters in the air and is a good value for the air quality around areas like a road or intersection. Both of these values are expressed in a kg/h.
Waiting time for cars and cyclists (Traffic flow)

The final parameters address the area of traffic flow. Again, there are two separate parameters which will be used in the MCA. They both address the travel time of road users. Or the waiting time for cars and cyclists to be more specific. The simulation model gives clear values about the (average) waiting times for both cars and cyclists passing the intersection. These parameters could easily be used in an MCA, as they are the same dimension for each intersection, namely the waiting time in seconds per car or cyclist.

Finally, here is an overview of the six parameters which will be used for the comparison in the MCA.

- Number of Critical Conflicts per car, per bike.
- Chance of a fatal crash based on the average speed.
- CO\(_2\) emission per car.
- PM\(_{10}\) emission per car.
- Waiting time per car.
- Waiting time per cyclist.

All these values will be calculated for each intersection and compared within the Multi Criteria Analysis.

Final words for chapter four

Chapter four showed the possible research methods available to collect the required data needed to answer the research questions. Eventually it was decided to use camera observations to gather data in regard to the traffic safety parameters, based on both the conflict observation and speed measurements. The data required for the other criteria, traffic flow and environment, could also be obtained by outdoor measurements. Due to time constraints, the choice was made to use a simulation tool to gather this data instead. Finally, a comparisons method was selected, namely the MCA method. This also involved selecting the different parameters used in this MCA. With the choice for the above mentioned research methods, it is possible to execute them. The next chapter will show how these methods have been used to collect and analyze the data for both the field work and the simulations for both the intersection in Heerhugowaard and Purmerend. The chosen comparison method will not be used in the next chapter. Instead, this is shown in chapter six.
Chapter five will go into more detail about the collecting and analysis of the data used for this study. The first part of this chapter will address the circumstances in which both the field work and the simulations took place. The second part will give an analysis of the results of both the field work data, as well as the simulation data.

5.1 Data collection

This paragraph will describe the circumstances under which the camera observations took place. Second, it will describe the values used in order to run the simulations.
5.1.1 Field work, pleintjes

At Wednesday the 10th of October, the first camera observation took place at the Pleintje in Heerhugowaard. After setting up the cameras, observations started around 7:40 and continued to 15:30. During the day there were good weather conditions with a clear blue sky.

The measurement truck was parked partially on the separated bike track and partially in the soft shoulder of the road. One camera was focused on the first cyclist crossing, while the other was aimed at the other. An overview of the measurement truck location, as well as the camera view can be seen in Figure 5.1. There were no trees or bushes covering the truck, so it was observing the intersection in clear sight.

During the day, measurements took place without any interruption, neither by outside, nor inside influences. One thing worth mentioning though, is the fact that at the adjacent roundabout, a police control took place during the first two hours of the observation. This only involved traffic driving away from the observed intersection. However, there is a chance that drivers noticed the police control and assumed the camera observation was part of it as well, hence adjusting their behaviour. However, the actual effects this may have caused are unknown.

Figure 5.1: Camera position at the pleintje in Heerhugowaard.
During Wednesday the 31st of October, the pleintje in Purmerend was observed. The observation itself started at 7:30 and continued non stop to near 15:30 again. The weather condition during the day was clouded, but apart from a few drips near the end of the morning, it remained dry.

The measurement truck was placed nearby the intersection on a wide sidewalk next to a shopping mall. The first camera was focused on the nearby cyclist crossing, while the other was directed to the second. An overview of the measurement truck location, as well as the camera view can be seen in Figure 5.2. There were some young trees covering the sight from to road towards the truck, but the installation was still rather visible.

The measurements ran almost without any interruption. There was only a small problem during the morning when the aggregate stopped working and power was lost. This problem was fixed rather quickly however, so only a few minutes were missed during that time. The rest of the day passed without any noteworthy events.

Figure 5.2: Camera position at the pleintje in Purmerend.
5.1.2 Field work, priority intersections

During Tuesday the 23rd of October, the priority intersection in Heerhugowaard was observed with the cameras. Observations started at 7:55 and lasted until 15:15. Observation started a little later than usual due to it still being too dark at first. During the day, weather was clouded at first, with a little drizzle during the morning. As the day progressed, the sky cleared up again and weather conditions changed to good. The truck was parked at some distance from the intersection, part on the sidewalk and part on the bicycle path. As with the pleintjes, one camera was focused on the first crossing, while the other was directed to the second crossing. An overview of the setup can be viewed in Figure 5.3. There were some almost leafless trees slightly covering the truck, but in general it was not hidden from sight.

The observation took place without any incidents during the day. The only problem that arose was the reflection of light into one of the cameras. This caused the image to be rather useless, as if there was a thick fog. Luckily, the truck was parked at significant distance from the intersection, so it was possible to observe the entire intersection with the other camera. Apparently, this camera was not influenced by the reflecting sunlight and further observation went without any problems.

![Figure 5.3: Camera position at the priority intersection in Heerhugowaard.](image)
Two days later, Tuesday the 25th of October, the priority intersection in Purmerend was observed. The observations started a little after 8:00 and lasted till 15:30. Weather conditions were slightly clouded, but it remained dry during the day. The truck itself was placed partially on the sidewalk and partially in the soft shoulder of the road. One camera was focused at the intersection, giving a good view parallel to that of the main road. The second camera was aimed more towards the side street. The used observation setup can be seen in Figure 5.4. No foliage covered the view on the truck, so it was observing the intersection without in clear sight. During the observations, nothing significantly happened and all data was collected without any problems. However, when the data was processed later, one of the hard disks containing the data broke down. After some repairs, part of the data was recovered, but all observations after 13:00 were lost in the process.

Figure 5.4: Camera position at the priority intersection in Purmerend.
5.1.3 Field work, roundabouts

At Thursday the 11th of October, the second camera observation took place at the roundabout in Heerhugowaard. After setting up the cameras, observations started around 7:30 and continued to 13:30. Observations were cut short this day, as plenty of conflicts had been observed during this period, due to a high number of cyclists crossing the road at this intersection. During the day there were good weather conditions with a clear blue sky.

The measurement truck was parked partially on the separated bike track and partially in the soft shoulder of the road. One camera was focused on the first cyclist crossing, while the other was aimed at the other. An overview of the measurement truck location, as well as the camera view can be seen in Figure 5.5. There were no trees or bushes covering the truck, so it was observing the intersection in clear sight.

During the day, measurements took place without much trouble. Unfortunately, one of the cameras had the same light fall problems as with the priority intersection in Heerhugowaard. Luckily, it only influenced part of the image, mainly blocking the non-important areas of the image. Second, for an hour (around 11:00), government gardeners started working on the flowerbeds at the intersection. This may have influenced the traffic flow, as the people working there in plain side may have distracted the drivers, possibly slowing them down for safety issues. If this had any major effects is unknown however.

Figure 5.5: Camera position at the roundabout in Heerhugowaard.
The final observations took place at Wednesday the 7th of November at the roundabout in Purmerend. Observations started at 7:30 and lasted until 15:20. Weather conditions were to worst at this day, with a light drizzle during most of the day, alternating with dry periods.

The observation setup was placed in the side street, on the sidewalk and bicycle path of a bridge, so it was placed in clear sight without any cover. One camera was aimed to the right side, focusing on one crossing, while the other camera was turned to the left, observing the other crossing. Figure 5.6 shows the setup again.

During the day, measurements took place without any interruption, neither by outside, nor inside influences. One thing worth mentioning though, is the fact that the cameras were not placed as high as at the other locations. The reason for this is that otherwise nearby trees would have blocked the view. Therefore, the view on the roundabout was less from above and more ‘flat’. As a result, this made the analyzing of the data afterwards slightly more difficult compared to the other intersections.

Figure 5.6: Camera position at the roundabout in Purmerend.
5.1.4 Simulations

In order to run the simulations, several values have to be entered. Most adjustable variables have been left in their default values as explained in paragraph 4.2.4. This leaves the geometry and intensities to be filled in. The geometry of the intersections have been determined and are put into the model. Next to that, both cyclist and traffic volumes have been counted based on the video material. For an equal comparison, one of these intensities is chosen for both the Heerhugowaard and the Purmerend situation, meaning each set of 3 intersections is simulated with the same intensity values. For both cities, the intensity values of the roundabout have been used.

In Figure 5.7 and Figure 5.8, the used O/D matrices for both cities are given. The first is from the roundabout in Heerhugowaard, where the second displays the Purmerend situation. On the left side, the O/D matrix for cars is given, while the right shows the bicycle O/D matrix.

![Figure 5.7: OD matrices for the Heerhugowaard simulations.](image)

![Figure 5.8: OD matrices for the Purmerend situations.](image)

A special note has to be made for the simulation of the Heerhugowaard priority intersection. As the tool only allows for a selection out of ten predefined intersection designs, it was not possible to completely copy this intersection into the simulation tool. Unlike the others, where one of the available designs matched the real counterpart. The main reason this doesn't work with the priority intersection are the double lanes on the main road. Such a design is not included in the predefined set of intersection. This was 'solved' by selecting the standard single lane priority intersection design and increase the width of the median island, as well as the length of the left turning lanes in order to compensate for the absence of the dual lanes.
5.2 Data analysis Heerhugowaard

This paragraph will address the first analysis of the Heerhugowaard data gathered during the camera observations in the field as well as the simulations.

5.2.1 Field work, pleintje

The first intersection being analyzed is the pleintje. The observations took place on Wednesday the 10th of October at the pleintje in Heerhugowaard.

General overview

The main flow of traffic travelling over the Westtangent in both directions could easily pass the intersection. This is more or less expected, as they have full priority over the other users at the intersection. Traffic crossing the street, both motorized and cyclists/pedestrians, have to give right of way to the main flow, resulting in waiting times to cross. If this exceeds the limits set for crossing has not been determined, but it seemed like there were enough gaps in traffic to cross. However, an interesting observation was the effect different downstream situations had on the available gaps. On one side, there is a roundabout leading to a steady stream of traffic. On the other side there was a controlled crossing for vulnerable road users, resulting in platoons. The controlled crossing made sure there were plenty of gaps in traffic from their side, while this was less the case from the other. It wouldn't be a surprise if waiting times would differ for crossing each lane.

Another interesting observation was that of the traffic flow around the centre island. It appeared that both streaming areas offered enough space for cars turning left in order for them not to block the main road. The only time this did happen was when the bus coming from the Umbriellaan had to turn left onto the Westtangent. Due to the size of the vehicle, its back end did block part of the road. A second observation that caught attention is the rumble strip that is used to ease the movement for trucks and buses making a left turn at the intersection. It appears the rumble strip is not annoying enough for normal cars, as almost all drivers use the rumble strip instead of the normal asphalt, cutting the corner. Even though this has not lead to any dangerous situations, it remains questionable if this is a desired effect, as it may lead to higher speeds due to a more fluent driving line.

Speed measurements

For the pleintje, a total of 800 cars have had their speeds measured, divided evenly over both driving directions. Meaning 400 measurements in one direction and another 400 for the other. Each of the cars had their speed measured twice, once while approaching the intersection and once leaving the intersection, both near the vulnerable road users crossings. From the results, it appears there is no significant difference in speeds when comparing both driving directions with each other. The same can be said when comparing the approach and leaving speeds. Therefore the average driving speed over the intersection results in approximately 46 km/h.
The v85 appears to be slightly higher, resulting in a value of a little over 50 km/h. The selected maximum speed of 50 km/h therefore seems legit, as the majority of the drivers comply with this. However, this would be a good result if it were a regular road section. At intersections, speeds are preferably lower, due to the interactions with merging/diverging and crossing traffic.

The difference between the average speed and the v85 also leads to the question of the homogeneity of the traffic. The maximum measured speed at the pleintje is close to 70, while the minimum speed is around 32. These could be extreme values though. Determining the standard deviation leads to a value of roughly 4.75 km/h. The bandwidth of the speeds, both approaching and leaving the intersection, is also shown in Figure 5.9 and Figure 5.10. In these figures it can be seen that the minimum and maximum values are indeed two extremes. However, there is still a bandwidth of 10 - 15 km/h.

Figure 5.9: Approach speeds at the pleintje in Heerhugowaard.

Figure 5.10: Leaving speeds at the pleintje in Heerhugowaard.
Conflict observation
The last part of the field work analysis consists of the observed conflicts. For the pleintje, a total of 289 encounters have been observed. This can be divided into 135 encounters between cyclists crossing the main road and cars approaching the intersection, 136 encounters between cyclists crossing the main road and cars leaving the intersection and 18 encounters between cyclists crossing the side street and a car leaving the intersection. For the first two types, the car has priority. While with the last type, the cyclist has right of way. Furthermore, it has to be noted that is only allowed to cross the main road in one direction, even though observations show cyclists tend to ignore this rule.

Most of the encounters do not result in a conflict as the priority rules are obeyed and the cyclist waits for the car to pass (or the other way around in case of the side streets). In fact, there has only been one critical conflict. In this case, a cyclist decided to cross right in front of an approaching truck, which in return brakes heavily. Next to this one critical issue, there have been a number of other cases that are considered as being a conflict. On 8 occasions, a cyclist unlawfully took priority. The main reason for this seemed to be a long waiting time, thus accepting a smaller gap than usual. Another possible reason for taking priority, crossing the second lane right after the first one, was only observed in one occasion. All of these conflicts however resulted in the approaching car having to brake. There was also one registered case of a car taking priority over a cyclists while turning right. The cyclist did notice this in time and took an evasive action by slowing down.

Another set of interesting conflicts is where both the car and the cyclist take an evasive manoeuvre, usually by slowing down. This was the case for 7 encounters. In all cases, the car received priority in the end. The main reason for slowing down was that the cyclist was still moving and waited with braking until the last moment. Whenever a cyclist had stopped in time, no car was seen slowing down. In general, it did not seem like cars would slow down whenever a cyclist was waiting or slowly approaching. Only in the few cases mentioned above, a braking manoeuvre was observed.

Recent discussion has also mentioned cars giving priority to cyclists while this is not required. This is classified by some as unwanted behaviour, as it may lead to head tail collisions between cars. During the observation, this has only happened three times. On one occasion the car slowed down, gave priority to the cyclist, then continued on the main road. In the second, the car had to slow down anyway, as he was about to make a right turn. During the last, a car just merged onto the main road and was still driving rather slow when it gave priority to the crossing cyclist.

Finally, the effect of cyclists driving against the driving direction has been taken into account. Even though crossing the main road is marked in one direction, not all cyclists follow this rule. However, based on the observation, cycling against driving directions has not lead to a higher amount of (critical) conflicts. The percentage of conflicts involving cyclists driving against direction is roughly the same as the percentage of all encounters with cyclists driving against directions compared to the total amount of encounters.
5.2.2 Field work, priority intersections
The second intersection being analyzed is the priority intersection. The observations took place on Tuesday the 23rd of October in Heerhugowaard.

General overview
At first sight, the priority intersection operates quite similar to the pleintje. Priority rules are the same, which gives right of way to the cars on the main flow and makes it run mostly undisturbed. However, there is a big difference to the solution in the centre. Compared to the pleintjes centre island, there is just one slab of asphalt between both driving lanes that forms the streaming area for cars waiting to turn left. This space however is usually rather unclear and leads to many chaotic situations. Cars turning left from opposite lanes pass each other on both sides in different situations and it is not uncommon that waiting cars cause spillback on the main road. In the end, the problems always solve itself, but the fluent traffic flow seen at the pleintje is absent at the priority intersection. As mentioned above, motorized traffic having to cross the main flow has some problems. As with the cyclists crossing, exact waiting times have not been measured so there is little to say about.

An important aspect to mention is the fact that at one side of the intersection, a railway crossing is located. This may lead to slower speeds when cars drive towards a closed crossing, as they will have to wait anyway. With the railway crossing on one side and a signalized intersection on the others, cars often arrive at the intersection in platoons, resulting in plenty of gaps for other (slow) traffic to cross the street.

Speed measurements
The priority intersection has seen a total of 770 cars, equally divided over both directions resulting in 385 measurements per direction. Again, each car has been measured twice. Once approaching the intersection and once leaving. Just like the pleintje, it appears there is little to no difference between cars approaching and leaving the intersection, neither does the driving direction have an influence on the speed. On average the measured speed of the cars passing the intersection is close to 48 km/h. The v85 of the priority intersection is slightly different for cars approaching and leaving the intersection. The v85 for approaching cars is around 52 km/h, while the v85 for cars leaving the intersection is slightly higher at 54 km/h. Again, this is near the speed limit of 50 km/h, but at an intersection, lower speeds are preferred.

This difference between approaching and leaving cars can also be seen in other parameters. The maximum and minimum speeds to approaching cars are 70 and 31, while that of leaving cars are 72 and 27. This could mean the speed variance for approaching cars is smaller compared to that of cars leaving the intersection. However, taking the standard deviation into account, it appears both values are roughly the same with 5.60 versus 5.84, suggesting there is no real difference in homogeneity of traffic between cars approaching or leaving the intersection. This is backed up by the figures of the speed bandwidth (Figure 5.11 and Figure 5.12), which are rather similar. The bandwidth for most speeds appears to have a width of 15 - 20 km/h.
A comparison between the plentje, priority intersection & roundabout

Figure 5.11: Approach speeds at the priority intersection in Heerhugowaard.

Figure 5.12: Leaving speeds at the priority intersection in Heerhugowaard.
**Conflict observation**

At the priority intersection, a total of 411 encounters have been observed. A 165 of those have been between cyclists crossing the main road and cars approaching the intersection. 176 were between cyclists crossing the main road and cars leaving the intersection. The final 70 encounters have been between cyclists crossing the side street and cars driving into the side street.

The majority of encounters saw no problem as the one having priority received it. However, there has been a total number of 6 critical conflicts. All of these cases are related to cyclists crossing the main road. Even though cyclists are allowed to cross the street in two directions, all but one of these conflicts saw cyclists driving in the 'normal' direction. As with the pleintje, cycling against the direction did not result in a higher amount of conflicts. In 2 cases, the bike took priority. In the other 4 of these critical cases, the car eventually received priority after having to brake fiercely at first. The reasons for this is that the cyclists somehow didn’t notice the car in time and braked to late as a result. In 2 cases the cyclist was already on the road and had to drive back a little to have the car pass first.

Apart from the two critical conflicts where a cyclist took priority, there were another 8 cases were the cyclist took priority, although with less serious consequences. It still forced the car to slow down a little. Half of these cases were due to the fact that cyclists simply continued their way without stopping like they should have. The other half was because they probably felt like they had waited too long and thus accepted a smaller gap to cross the street.

The other interesting type of conflicts are those were both the car and cyclist have to brake. There have only been four of these occasions, were three have already been mentioned as a critical conflict. The last one was one of the conflicts were a cyclist took priority. It first slowed down, then decided to accept the gap anyway and taking priority as it wasn’t large enough forcing the car to brake as well.

Last, there have again been a few occasions were priority was unrightfully given to a cyclist by a car. A total of 9 of these situations have been observed. From these situations, 6 were of the case again that a car was already slowing down to make a turn or it was still driving slow as it was merging onto the main road. The other 3 have been cases were a car gave priority to a cyclist and then continued his way on the main road.

**5.2.3 Field work, roundabouts**

The final Heerhugowaard intersection being analyzed is the roundabout. The observations took place on Thursday the 11th of October.

**General overview**

The general traffic flow of the roundabout is quite different from the other two intersections. The main reason for this is that the main road does not have priority like it has with the others. In stead, only traffic on the roundabout itself has priority. Next to that, cyclists have priority on all crossings, including the ones crossing the main road. As a result, the traffic flow on the main road is seriously reduced compared to the other intersections. It is seen quite often, especially during rush hour, that a long queue of cars appears on the main road. Cyclists take priority at the intersection, forcing the cars to wait.
The main advantage of this intersection lies in the fact that vulnerable road users are free to cross the street when they see fit. There are no waiting times, as they have priority and should be able to cross immediately when they arrive. Motorized traffic from the side streets are in the same situation as the cars driving on the main route, as all four branches are equal.

Another general observation that was specific for the roundabout has been the apparent conflicts. In these cases, cars slowed down as they were unsure if they had to give either a cyclist or another car priority. These conflicts have not been recorded, but appeared more then a few times.

**Speed measurements**

The roundabout has seen 528 cars pass that had their speed measured. The only cars counted were those that could pass the intersection without interference from cyclists and continued on the main road. As this only happened 528 times, the total dataset is smaller compared to the pleintje and the priority intersection.

The 528 cars have been divided equally over both directions resulting in 264 cars measured for each direction. Again, all cars were measured twice. Once approaching and once leaving the intersection. This time, there have been some differences in the speeds. The leaving speed of the roundabout is a little higher compared to the approach speed. The driving direction did not have any significant influences on the speeds. The average approach speed of the roundabout is 28 km/h, while the average leaving speed is higher at 31 km/h.

As with the average speed, there is also a difference in v85 speeds, although the difference is smaller. The v85 for approaching cars is 33 km/h while it is 34 km/h for cars leaving the roundabout.

This difference can also be seen with the other parameters, and in the same ratios. The minimal and maximal speed for approaching vehicles are 17 and 43 km/h respectively and for cars leaving the roundabout these values are at 20 and 47 km/h.

The standard deviation also backs up these difference, being 4.25 for approaching vehicles and 3.56 for cars leaving the roundabout. This would mean that traffic leaving the roundabout would be more homogenous compared to traffic approaching the roundabout. It could be that cars arrive at different speeds and brake later or earlier than others. When leaving the roundabout, they have roughly the same accelerating curves, meaning a more similar speed pattern. The bandwidth figures also seem to back these statements up (Figure 5.13 and Figure 5.14). The bandwidth of the approach speed seems a little over 10 km/h, while the bandwidth for the leaving speeds seems close to, or even at 10 km/h.
Figure 5.13: Approach speeds at the roundabout in Heerhugowaard.

Figure 5.14: Leaving speeds at the roundabout in Heerhugowaard.
Conflict observation

During the observation of the roundabout a total of 528 encounters were witnessed. From this total, 221 of these encounters were between a cyclist crossing the main road and a car approaching the roundabout. Another 250 were between a cyclist crossing the main road and a car leaving the intersection. The remaining 54 encounters were between cyclists crossing the side street and a car entering this same road. In general, most encounters went down without too much trouble, but there were still 8 encounters that have been marked as a critical conflict. In all but one of these cases, the cyclist was driving against the normal traffic direction, even though this is allowed at the roundabout. In half the cases, both the car and cyclist had to brake, while in the other half, only the car took an evasive manoeuvre by braking. In all cases, the bike eventually passed first. The main reason for these critical conflicts is most likely that the car driver didn't noticed the cyclist coming from the opposite direction quick enough, resulting in an emergency stop from the car as well as evasive manoeuvres by the cyclist.

When looking at the 'illegal' priority conflicts, it is shown that in 21 cases a car took priority. Again, as with the critical conflicts, the majority, 18, were conflicts were the cyclist was driving in the opposite direction. There have been two main causes for these actions. The first involves cars waiting for a longer period, eventually taking a smaller gap than normal. The second reason is linked again to the car driver not noticing the cyclist approaching from the opposite direction.

Finally, there have been a number of cases where both the car and the cyclist had to slow down. 23 to be precise. The first 4 of these conflicts have been marked as a critical conflict already. The other 19 are not marked as such, but still had both conflict participants taking evasive manoeuvres. Again, the vast majority of these cases are related to conflicts were the cyclists is driving in opposite direction. In all these cases, the cyclist eventually was allowed to pass first. The main reason for the cyclist to slow down was the fact that they seemed unsure if the car had noticed them and that they would indeed receive priority from them.

There have been no cases of cyclists giving priority to cars. This is quite different from the other two intersections, which is mainly explained by the fact that the priority situation is different. Another interesting difference between the pleintje and priority intersection on one hand and the roundabout on the other, is the influence of cyclists driving against direction. The number of (critical) conflicts on the first two intersections was in line with total amount of encounters involving cyclists driving against direction compared to the total amount of encounters. For the roundabout however, the amount of (critical) conflicts involving cyclists driving against direction was significantly higher than the amount of encounters involving cyclists driving against direction compared to the total amount of encounters.
5.2.4 Simulations, pleintje
The output files of the simulation consists of quite a few interesting data. However, as mentioned in the previous chapter, only a few will be used in the comparison. Therefore, each of the simulation paragraph will just list the relevant parameters. A small explanation may be in order though. The first two parameters are the average waiting times for cars and cyclists at the intersection. This means the average waiting times for all cars and cyclists, both on the main road as well as on the side street. The same goes for the environmental parameters, where the values represent the total stops and emissions for all cars passing the intersection during the simulation. The results for the pleintje based on the simulation are the following.

Traffic flow
Average waiting time for a car at the intersection: 3.6 seconds
Average waiting time for a cyclist at the intersection: 3.6 seconds

Environment
Number of stops by car at the intersection: 93
Emission of CO$_2$: 109.3 kg/h
Emission of Pm$_{10}$: 1.30

5.2.5 Simulations, priority intersections
For the priority intersection, the following results have been produced.

Traffic flow
Average waiting time for a car at the intersection: 3.3 seconds
Average waiting time for a cyclist at the intersection: 4.2 seconds

Environment
Number of stops by car at the intersection: 12
Emission of CO$_2$: 100.3 kg/h
Emission of Pm$_{10}$: 1.16
5.2.6 Simulations, roundabouts

An interesting observation for the roundabout simulation was the fact that the observed queues are also returning in the simulation. The same can be said for the other intersections, although there were no clear points to compare the real world situation with the model, like these queues for the roundabout. This would indicate, that the simulation tool is indeed a good method in order to obtain data about the intersections. For the roundabout, the following results have been produced.

Traffic flow
Average waiting time for a car at the intersection: 6.4 seconds
Average waiting time for a cyclist at the intersection: 0.0 seconds

Environment
Number of stops by car at the intersection: 214
Emission of CO₂: 131.0 kg/h
Emission of Pm₁₀: 1.70
5.3 Data analysis Purmerend

This paragraph will address the first analysis of the Purmerend data gathered during the camera observations in the field as well as the simulations.

5.3.1 Field work, pleintje
The first intersection being analyzed is the pleintje. The observations took place on Wednesday the 31st of October at the pleintje in Purmerend.

General overview
First impressions of the pleintje are good. Traffic flowed over the Churchilllaan without too much trouble. The pleintje itself performed as expected, handling all the traffic with relative ease. There were a few times when the left turning traffic did block the main road. This is also to be expected as there is a relative high amount of traffic turning left into the side street, including a fair number of buses. Since the pleintje can only buffer one or two cars, a left turning bus will almost always block the main road if it has to wait. Since the design of the island does not separate both left turning movements like the other pleintje, they sometimes hinder each other.
This has also to do with the downstream situations. The railway crossing on the one side queues up a number of vehicles which eventually are all driving towards the pleintje in one go. With such a high number of vehicles arriving shortly after each other, traffic may slow down when a few of these vehicles want to turn left. From the other side, the roundabout makes the traffic arriving in a more continues way. Crossing the streets is usually no problem as there are plenty of gaps in traffic. Sometimes even forced ones as the railway crossing forces cars to wait. From the other direction a zebra crossing between the roundabout and the priority intersection has the same effect. The most used cyclist crossing at the pleintje is the one crossing the side street, which is where they have right of way.
Two other interesting observations were made as well. The first involved cyclists coming from the roundabout. They avoided the intersection all together, taking a route via the nearby parking lot. Most likely because they felt this was shorter. The second observation is about trucks coming from the side street wanting to turn right. A few did not believe they could make this turn. Instead, they turned left, made a 180 turn at the roundabout and continued straight through over the pleintje.
Speed measurements

At the pleintje, a total of 800 cars have had their speeds measured, divided equally over both driving directions. This results in 400 measurements in one direction and 400 in the other. Every car has had its speed measured twice, one during approach and one after leaving the intersection, both near the vulnerable road users crossings. The results show no significant differences in car approaching or leaving, neither does the driving direction have an influence. The average driving speed therefore results in roughly 43 km/h.

The v85 is again higher, close to 48 km/h. The local speed maximum of 50 km/h is therefore a properly chosen speed limit, as it seems the majority of the road users are complying with this speed limit. But as with the pleintje in Heerhugowaard, the speeds are still higher than preferred at an intersection to be considered 'safe' in regard to crossing (slow) traffic.

The minimum and maximum speed are 29 and 62 km/h respectively. Compared to Heerhugowaard, it is noticeable that especially the maximum speed is a lot lower (almost 10 km/h). This lower maximum speed would raise the question if the traffic at the Purmerend pleintje is more homogenous as well. Looking at the standard deviation this is not the case, as it is again 4.75 km/h. The bandwidth figures, Figure 5.15 and Figure 5.16, confirm this, as there is again a bandwidth of roughly 10 - 15 km/h.

![Approach speeds pleintje](image)

**Figure 5.15: Approach speeds at the pleintje in Purmerend.**
A comparison between the pleintje, priority intersection & roundabout

Conflicts observation

The final part of the field work analysis is the conflict observation. For the pleintje in Purmerend a total of 271 encounters have been observed. They can be divided into 78 encounters where a cyclist is crossing the main road and a car is approaching the intersection, 110 encounters with a cyclist crossing the main road and a car is leaving the intersection and a final 83 encounters when a cyclist crosses the side street and a car is entering that road. As at the other pleintje, with the first two types the car has priority, while in the last type, the cyclist has priority.

The majority of the encounters did not result in a dangerous situation as one or the other took appropriate action in time. On two occasions a critical conflict was observed. In both cases, a car was turning left from the main road and into the side street. It had probably missed the cyclist and almost hit it on both occasion, braking just in time as well as the cyclist making an evasive manoeuvre.

Next to these critical conflicts, a number of other cases are considered conflicts as well. On 3 occasions, a cyclist took priority while crossing the main road. This forced the approaching car to brake suddenly. The main reason for this was that the cyclist did not bother to stop and just continued their way.

On another 13 cases, both the approaching vehicle and the crossing cyclist slowed down. Most of these conflicts happened while a cyclist was crossing the side street. The main reason for this was that the cyclist seemed unsure if they would receive priority meaning if the car had actually noticed them or not.

In the discussion of cars giving priority to cyclists when it is not needed, it could be seen that this happened in 16 cases. In 5 cases, a car slowed down, gave the cyclist priority, then continued on the main road. But in the other 11 cases, the car had to slow down anyway, either because it had to turn left, or because there were other cars blocking the road who were waiting to turn as well.

Finally, the effect of cyclists driving against direction on the number of conflicts has been analyzed. It can be seen that driving against direction did not lead to an higher amount of conflicts because of it. The percentage conflicts while driving against direction was roughly the same as with the percentage of encounters involving cyclists driving against directions compared to the total amount of encounters.
5.3.2 Field work, priority intersections

The second intersection being analyzed is the priority intersection. The observations took place on Thursday the 25th of October in Purmerend.

General overview

The priority intersection in Purmerend worked as intended, even though this was to be expected. Analyzing the recordings, it appeared that the intensity on this intersection was a bit lower than its two counterparts in Purmerend. This resulted in less ‘exciting’ observations as nothing special happened in general. Only the odd bus turning which blocked traffic as the centre island was not even big enough to provide enough buffer space for a car, let alone a bus.

Crossing the street was no problem at all and could be done without much waiting time. The small centre island did cause for a few minor problems though. As it could barely store a bicycle, this caused the cyclists to sometimes wait partially on the road. In one or two occasions this caused an approaching car to slow down and pass with reduced speed.

Speed measurements

Unlike the roundabout and the pleintje, the priority intersection only had 591 speed measurements. This is mainly because part of the footage was lost when the hard disk crashed. On the remaining videos there were simply not enough cars to measure. From the 591, 300 have been measured in one direction, while 291 cars were measured in the other direction. Based on the results, it did not matter if a car was approaching or leaving the intersection. It did not matter much either in which direction it was driving. Taking this into account, it can be noted that the average speed of cars passing the vulnerable road users crossings was roughly 47 km/h.

The v85 is again the same for both approaching and leaving vehicles. Both measuring around 53 km/h. This is only slightly above the maximum speed of 50 km/h, which shows it is a legit chosen speed limit. However, as with the pleintje, the conflict speed at the slow traffic crossings is preferably a lot lower when considering their safety.

The maximum measured speed is a lot higher compared to the pleintje though, measuring 74 km/h. The minimum speed is also slightly higher at 32 km/h. This would mean traffic is less homogenous as the speed differences are larger. This is also backed up by the standard deviation being higher at 5.15 km/h, as well as by the bandwidth figures, Figure 5.17 and Figure 5.18. Although it can be seen that the maximum measured speed is a one off event, it still has a bandwidth of 15 km/h, which is larger than the pleintjes.
A comparison between the pleintje, priority intersection & roundabout

**Figure 5.17:** Approach speeds at the priority intersection in Purmerend.

**Figure 5.18:** Leaving speeds at the priority intersection in Purmerend.
Conflict observation
Due to the lost footage and relative lower traffic flows, the number of encounters (and conflicts) are quite a bit lower compared to the other two intersections. A total of 63 encounters have been witnessed. 23 encounters involved a car approaching and a cyclist crossing the main road, 32 encounters involved a car leaving the intersection and a cyclist crossing the main road, while the last 8 encounters involved an encounter between a car entering the side road and a cyclist crossing said road. As with the pleintje, the car has priority during the first two types, while the cyclist has priority on the last encounter type. The number of critical conflicts observed on this intersection has been zero, as no critical conflicts happened during the day.
However, there were a few encounters that can be noted as a conflict instead. On two occasions, a cyclist took priority forcing the car to brake quite heavily. Although the car did note this in time on both occasions, allowing it to take appropriate measures in time. The other type of interesting conflicts, the one where both the car and the cyclist take an evasive manoeuvre was not observed during the day.
There were a few encounters were a car would give priority to a cyclist crossing the main road. Again, the most common event that caused this was a car merging onto the main road, still driving slow anyway. This happened in 4 of the 5 cases. During the last, a car just slowed down, allowed the cyclist to cross first, then continued on the main road.
Finally, crossing the road in the wrong direction did again not lead to a higher amount of conflicts. Although with the small number of encounters and actual conflicts, not much can be said about it for this intersection.

5.3.3 Field work, roundabouts
The final Purmerend intersection being analyzed is the roundabout. The observations took place on Wednesday the 7th of November.

General overview
The roundabout in Purmerend worked like intended. Compared to the roundabout in Heerhugowaard, it did not show such long queues of cars waiting for cyclists to cross. The main reason for this is the fact that there are no that many cyclists crossing the main road. There is one heavy cyclist route, during the morning rush hour, but this involves the cyclists crossing the side street. Compared to the other two intersections, cyclists have priority on all crossings. Different to the roundabout in Heerhugowaard, the cyclists are only allowed to drive in one direction. Although in practice, cyclists just take the shortest route, whichever direction this may be. As cyclists had priority, it did not take much trouble crossing the street. They could just cross when arriving at the roundabout, assuming the car had slowed down for them.
Another interesting point that could be seen is the result of the design of the roundabout. Coming from the north (pleintje side) and continuing on the main road means that the turn a car has to take is relatively gentle. It does not force it to slow down the way it would when it hits the roundabout straight on. This can also be seen in a number of leaving speeds being rather high, as cars exit with a higher speed since their speed is not reduced much in the first place.
Speed measurements
For the roundabout, 800 cars have had their speeds measured, equally divided between both driving directions. Meaning 400 measurements each for both directions. Again, two measurements per car have been taken, both at the cyclist crossings. Based on the speed results, the driving direction did not matter much. Approaching or leaving the roundabout does. The average approach speed is 27 km/h, while the average leaving speed is 30 km/h.

The same differences can be seen in the v85. Cars approaching the roundabout have a v85 of 31 km/h, while cars leaving the intersection have a v85 of 34 km/h. This is quite a bit lower than the other two intersection types and more in the range of what is considered a safe conflict speed at an intersection.

The same difference can also be seen in the minimum and maximum speed. Approaching they are 17 km/h and 47 km/h, while cars leaving were measured at 19 and 49 km/h. Even though they may be extremes, it can be seen that the maximum speed difference is smaller compared to the other two intersections. This also follows out of the standard deviation, which is around 3.8 km/h. This is also backed up by Figure 5.19 and Figure 5.20, which show a bandwidth of a little over 10 km/h.

![Approach speeds roundabout](image)

Figure 5.19: Approach speeds at the roundabout in Purmerend.
Figure 5.20: Leaving speeds at the roundabout in Purmerend.

Conflict observation
The last part of the field work analysis consists of the observed conflicts. For the roundabout, a total of 288 encounters have been observed. These can be divided into 108 encounters between cyclists crossing the main road and cars approaching the intersection, 125 encounters between cyclists crossing the main road and cars leaving the intersection and 55 encounters between cyclists crossing the side street and a car leaving the intersection. In all cases, the cyclist has priority while crossing the street. Furthermore, it has to be noted that is only allowed to drive around the roundabout in one direction, even though observations show cyclists tend to ignore this rule and still drive in both directions.

Most of the encounters did not result in a dangerous situation as the priority rules are obeyed and the car waits for the cyclist to cross. However, on 4 occasions, this was certainly not the case. All these critical conflicts consisted of a car not noticing the cyclist crossing in time. In two of these cases it was the car that eventually took priority while the cyclist had to evade significantly. On the other two cases it was the car that was able to brake just in time, but only just.

Apart from the critical conflicts a number of other conflicts happened during the day. Next to the 4 critical conflicts, another 16 cars took priority where they should have given priority to the cyclist. Unlike the other roundabout, this was not only due to cyclists coming from the wrong direction, as this is only a small percentage. It will probably be the fact that the drivers simply missed the cyclists approaching regardless in which direction they were driving.
Another set of interesting conflicts is where both participants have to brake or take another evasive manoeuvres. This was the case with 3 of the critical conflicts, but happened with 10 other conflicts as well. Although less serious, it still caused some conflict. In all 10 cases, the cyclist was eventually allowed to pass first though. The main reason for these conflicts was the fact that the cyclist seemed unsure whether or not they would receive priority.

As cyclist have priority on all crossings, no cases were recorded were a cyclist was given unrightfully priority, neither did a cyclist give priority to a car.

Finally, the effect of cyclists driving against direction. Even though the separated bicycle path was in one direction, cyclists did drive in both directions. Even though the percentage of cyclist driving in the opposite direction involved in (critical) conflicts is higher than the total percentage of cyclists driving in the opposite direction com-pared to the total amount of encounters. This share is not as large as with the round-about in Heerhugowaard, but it is still an larger share compared to the other two intersection types.

### 5.3.4 Simulations, pleintje

As with the Heerhugowaard roundabout, an interesting traffic pattern was also seen in both the real world as with the simulation for the Purmerend pleintje. It was men-tioned before that the (high) amount of left turning traffic sometimes caused spillback on the main road. The same phenomena was observed in the simulation, giving another positive sign that the chosen model works as intended.

For the pleintje, the following results have been produced.

**Traffic flow**
- Average waiting time for a car at the intersection: 2.9 seconds
- Average waiting time for a cyclist at the intersection: 3.1 seconds

**Environment**
- Number of stops by car at the intersection: 36
- Emission of CO\textsubscript{2}: 50.0 kg/h
- Emission of Pm\textsubscript{10}: 1.21

### 5.3.5 Simulations, priority intersections

For the priority intersection, the following results have been produced.

**Traffic flow**
- Average waiting time for a car at the intersection: 2.4 seconds
- Average waiting time for a cyclist at the intersection: 3.4 seconds

**Environment**
- Number of stops by car at the intersection: 21
- Emission of CO\textsubscript{2}: 48.1 kg/h
- Emission of Pm\textsubscript{10}: 1.04
5.3.6 Simulations, roundabouts
For the roundabout, the following results have been produced.

Traffic flow
Average waiting time for a car at the intersection: 2.7 seconds
Average waiting time for a cyclist at the intersection: 0.0 seconds

Environment
Number of stops by car at the intersection: 63
Emission of CO$_2$: 70.5 kg/h
Emission of Pm$_{10}$: 1.71

Final words for chapter five
The last chapter described how the data required to answer the research questions was collected and analyzed. This meant that the circumstances during the camera observation have been described. And if applicable, what went wrong during the observation or have there been any exterior factors which may have influenced the measurements. For the simulations at first the simulation parameters have been presented. Which boundaries are given to the simulation tool on which it will run the simulations. In the second part the data was analyzed for both the Heerhugowaard and Purmerend intersection. Both the results from the camera observations, as well as the simulation runs are presented for each intersection.
The next chapter will continue with these results. Chapter six consists of the comparison aspect of this study, where the results of the data collection and analysis is used to compare the different intersections with each other on the different criteria.
6 Comparison

The following chapter will address the comparison between the three intersections. At first, the different aspects traffic safety, traffic flow and environment will be discussed. Finally, a total comparison will be made.

6.1 Comparison in safety aspects

The first aspect which will be addressed is the traffic safety aspect. This aspect is split into two different parts, namely the risks and the effects. Both are gathered via the camera observations. The first is determined based on the conflict observation, while the second is based on the speed measurements.

6.1.1 Risks

Based on the conflict observation, each intersection has seen a certain number of encounters and (critical) conflicts. In Table 6.1 and Table 6.2 an overview for both Heerhugowaard and Purmerend is given.

<table>
<thead>
<tr>
<th>Heerhugowaard</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encounters</td>
<td>289</td>
<td>411</td>
<td>525</td>
</tr>
<tr>
<td>Conflicts</td>
<td>16</td>
<td>14</td>
<td>44</td>
</tr>
<tr>
<td>Critical Conflicts</td>
<td>1</td>
<td>6</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 6.1: Encounters and conflicts in Heerhugowaard.

<table>
<thead>
<tr>
<th>Purmerend</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encounters</td>
<td>271</td>
<td>63</td>
<td>288</td>
</tr>
<tr>
<td>Conflicts</td>
<td>15</td>
<td>2</td>
<td>32</td>
</tr>
<tr>
<td>Critical Conflicts</td>
<td>2</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 6.2: Encounters and conflicts in Purmerend.
However, all these values are not ready to be compared yet, as there is one major issue. The number of encounters and conflicts is closely linked to the traffic volume of both cars and bicycles. In order to compare them properly, the values have to be divided by the intensities of cars and bicycles so there is one common value of the number of encounters/conflicts per car per bike. As these values become rather small, the final comparison is also given in a percentage between brackets. Further details about this calculation can be found in Appendix B. In Table 6.3 and Table 6.4, these results are shown for both Heerhugowaard and Purmerend.

<table>
<thead>
<tr>
<th>Heerhugowaard</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encounters</td>
<td>0.001058 (100%)</td>
<td>0.001225 (116%)</td>
<td>0.000970 (92%)</td>
</tr>
<tr>
<td>Conflicts</td>
<td>0.000059 (100%)</td>
<td>0.000042 (71%)</td>
<td>0.000081 (139%)</td>
</tr>
<tr>
<td>Critical Conflicts</td>
<td>0.000004 (100%)</td>
<td>0.000019 (488%)</td>
<td>0.000013 (353%)</td>
</tr>
</tbody>
</table>

Table 6.3: Encounters and conflicts in Heerhugowaard.

<table>
<thead>
<tr>
<th>Purmerend</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encounters</td>
<td>0.002022 (100%)</td>
<td>0.001134 (56%)</td>
<td>0.000913 (45%)</td>
</tr>
<tr>
<td>Conflicts</td>
<td>0.000112 (100%)</td>
<td>0.000036 (32%)</td>
<td>0.000101 (91%)</td>
</tr>
<tr>
<td>Critical Conflicts</td>
<td>0.000015 (100%)</td>
<td>0 (0%)</td>
<td>0.000013 (85%)</td>
</tr>
</tbody>
</table>

Table 6.4: Encounters and conflicts in Purmerend.

Based on the conflict observations for the intersections in these two cities, a few interesting observations can be made. First off all, the roundabout scores significantly worse compared to the pleintje in Heerhugowaard. In Purmerend, the number of (critical) conflicts is slightly lower for the roundabout compared the pleintje. Interesting to note though, is the fact that the percentage of encounters is lower for the roundabout, but the following percentages for (critical) conflicts is a lot higher. This could mean that at the pleintje, most encounters when a crossing cyclist meets a car are resolved in a proper way, while at the roundabout this is more likely to result in a (critical) conflict. In fact, the percentage of critical conflicts in Heerhugowaard are even 3.5 times higher while the percentage of encounters is roughly the same. The second part is the comparison between the pleintje and the priority intersection. These values contradict each other quite a bit. In Heerhugowaard, the number of critical conflicts is almost 5 times as high, while in Purmerend there are none for the priority intersection. However, in Purmerend, part of the observation was lost.

In conclusion, based on these six intersections, it can be said that the risk for a cyclist crossing the street is highest at a roundabout. For the pleintje and the priority intersection, no definite answer can be concluded. Although, taking into account Heerhugowaard shows a complete picture and has the most accurate data, it would seem the risk at the priority intersection is higher compared to the pleintje. Note, if another intensity calculation method is used, as can be shown in Appendix B, the roundabout scores significantly worse compared to the pleintje in both Heerhugowaard and Purmerend. The differences between the pleintje and the priority intersection remain roughly the same regardless of the method used.
6.1.2 Effects

Next to the risk part of a potential conflict or crash, there is a second part, namely the effect. The main contributor to the effect when an crash happens is the speed of the car involved. The higher the speed, the bigger the chance at an serious injury or even a fatality. This can be seen in Table 6.5 and Table 6.6, where the average speed is given, as well as the corresponding chance of a fatality. This percentage is also visualized in Figure 6.1 and Figure 6.2, showing two speed vs. fatality rate graphs for both Heerhugowaard and Purmerend. In these two figures, the roundabout is marked red, the pleintje with blue and the priority intersection in green.

<table>
<thead>
<tr>
<th></th>
<th>Heerhugowaard</th>
<th>Purmerend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed (km/h)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pleintje</td>
<td>46</td>
<td>43</td>
</tr>
<tr>
<td>Priority intersection</td>
<td>48</td>
<td>47</td>
</tr>
<tr>
<td>Roundabout</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td>Fatality Risk</td>
<td>9%</td>
<td>7%</td>
</tr>
<tr>
<td></td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>3%</td>
<td>3%</td>
</tr>
</tbody>
</table>

Table 6.5: Average speed and fatality risk in Heerhugowaard.

<table>
<thead>
<tr>
<th></th>
<th>Heerhugowaard</th>
<th>Purmerend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed (km/h)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pleintje</td>
<td>43</td>
<td>43</td>
</tr>
<tr>
<td>Priority intersection</td>
<td>47</td>
<td>47</td>
</tr>
<tr>
<td>Roundabout</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td>Fatality Risk</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td></td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>3%</td>
<td>3%</td>
</tr>
</tbody>
</table>

Table 6.6: Average speed and fatality risk in Purmerend.

Figure 6.1: Speed vs. fatality rate for Heerhugowaard.
What can be seen for both these cases is that the roundabout scores the best by far. Its reduced speed significantly reduces the fatality risk compared to the other two intersections. In Heerhugowaard, the speed difference causes the chance at a fatality to be 3 times lower compared to the pleintje and the priority intersection. In Purmerend, this chance at a fatality is 2 times lower at a roundabout compared to the pleintje and again 3 times lower when compared to the priority intersection.

### 6.2 Comparison in traffic flow aspects

The second aspect which will be used to compare the intersections is the traffic flow. The main criteria are the average waiting times for both cyclists and cars at the intersections. With the use of the simulation tool, these values have been determined and presented in the previous chapter. In Table 6.7 and Table 6.8, an overview is given.

<table>
<thead>
<tr>
<th>Heerhugowaard</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waiting time car (s)</td>
<td>3.6</td>
<td>3.3</td>
<td>6.4</td>
</tr>
<tr>
<td>Waiting time bike (s)</td>
<td>3.6</td>
<td>4.2</td>
<td>0</td>
</tr>
</tbody>
</table>

**Table 6.7: Car and bike waiting times for Heerhugowaard.**

<table>
<thead>
<tr>
<th>Purmerend</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waiting time car (s)</td>
<td>2.9</td>
<td>2.4</td>
<td>2.7</td>
</tr>
<tr>
<td>Waiting time bike (s)</td>
<td>3.1</td>
<td>3.4</td>
<td>0</td>
</tr>
</tbody>
</table>

**Table 6.8: Car and bike waiting times for Purmerend.**
These values are the average waiting time per car or per bike and are all equal for each intersection, as each intersection is simulated with the same traffic volumes. Therefore, a direct comparison can be made. The first interesting point to note is the waiting time for bikes at the roundabout. Since they have priority on all branches while crossing, their waiting time is reduced to zero, as they should be able to cross as soon as they arrive at the crossing. Comparing the bicycle waiting times for the pleintje and the priority intersection they are obviously higher than the roundabout. Simply because cyclists do not have priority when crossing the main road, which leads to waiting times. When comparing the pleintje with the priority intersection, it can be seen that the pleintje scores a little better in both Heerhugowaard and Purmerend with slightly shorter average waiting times for cyclists.

When looking at the average waiting times for car, an interesting fact also appears. First, the waiting time on the priority intersection is lowest on both occasions. With the other two intersections, there is no definite conclusion. In Purmerend, waiting times for cars are more or less equal, with the roundabout scoring slightly better. In Heerhugowaard it is quite the opposite, with the roundabout scoring significantly worse. This is more in line with the expectations, as cars have to give priority to cyclists on all branches and therefore have more delays compared to the other intersections.

6.3 Comparison in environmental aspects

The final comparison aspect are the environment aspects. These are also determined with the simulation tool. Table 6.9 and Table 6.10 give an overview of the different environmental parameters for both Heerhugowaard and Purmerend.

<table>
<thead>
<tr>
<th>Heerhugowaard</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of stops</td>
<td>93</td>
<td>12</td>
<td>214</td>
</tr>
<tr>
<td>$\text{CO}_2$ (kg/h)</td>
<td>109.3</td>
<td>100.3</td>
<td>131</td>
</tr>
<tr>
<td>$\text{Pm}_{10}$ (kg/h)</td>
<td>1.3</td>
<td>1.16</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Table 6.9: Emission in Heerhugowaard.

<table>
<thead>
<tr>
<th>Purmerend</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of stops</td>
<td>36</td>
<td>21</td>
<td>63</td>
</tr>
<tr>
<td>$\text{CO}_2$ (kg/h)</td>
<td>50</td>
<td>48.1</td>
<td>70.5</td>
</tr>
<tr>
<td>$\text{Pm}_{10}$ (kg/h)</td>
<td>1.21</td>
<td>1.04</td>
<td>1.71</td>
</tr>
</tbody>
</table>

Table 6.10: Emission in Purmerend.
These values are the result of simulations with equal traffic volumes, making it possible to compare them straight away, just like the traffic flow parameters. A few interesting observations can be made based on these results. First of all, the comparison between the pleintje and the roundabout. In both Heerhugowaard and Purmerend it can be seen that there are a lot more cars stopping (obviously, as they have to give priority to cyclists), which also results in higher values for both CO\textsubscript{2} and Pm\textsubscript{10}. When looking at the differences between the pleintje and the priority intersection something interesting appears. Both the number of stops as well the CO\textsubscript{2} and Pm\textsubscript{10} are lower for both Heerhugowaard and Purmerend. This is odd, as the pleintje was originally intended to be beneficial to the environment. For Heerhugowaard this could be explained by the fact that the chosen priority intersection could not be implemented fully into the simulation tool. As for Purmerend, it is not know why this has happened, even though the differences between the pleintje and the priority intersection are not as large as in Heerhugowaard.

6.4 Total comparison between the intersection types

After taking a look at the individual aspects and compare those, the final step is to combine them all into one comparison. The next few paragraphs will do exactly that. First, a comparison based on percentages will be done, to rank the different intersections based on the different criteria. Second, a comparison will be made based on the same criteria, but the percentages are replaced by a monetary value.

6.4.1 Absolute comparison

The first total comparison is based on a percentage, where the pleintje is set at 100%. Both the priority intersection and the roundabout are ranked to the pleintje. This is just a random choice as it does not mean the pleintje is the reference point. In any case either the priority intersection or roundabout could have been set at 100% as well. But for the sake of comparison one of them was selected, in this case the pleintje. The criteria, as described previously are the following.

- Crash risk, based on critical conflicts observation and intensity.
- Fatality risk, based on the speed measurements.
- Average waiting time for a car, based on the simulation results.
- Average waiting time for a bike, based on the simulation results.
- Emission of CO\textsubscript{2}, based on simulation results and intensity.
- Emission of Pm\textsubscript{10}, based on the simulation results and intensity.

Table 6.11 and Table 6.12 give an overview of the total comparison for both Heerhugowaard and Purmerend, based on the criteria listed above.
A comparison between the pleintje, priority intersection & roundabout

<table>
<thead>
<tr>
<th>Heerhugowaard</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash risk</td>
<td>100%</td>
<td>488%</td>
<td>353%</td>
</tr>
<tr>
<td>Fatality risk</td>
<td>100%</td>
<td>111%</td>
<td>33%</td>
</tr>
<tr>
<td>Waiting time car</td>
<td>100%</td>
<td>92%</td>
<td>178%</td>
</tr>
<tr>
<td>Waiting time bike</td>
<td>100%</td>
<td>117%</td>
<td>0%</td>
</tr>
<tr>
<td>Emission of CO$_2$</td>
<td>100%</td>
<td>92%</td>
<td>120%</td>
</tr>
<tr>
<td>Emission of Pm$_{10}$</td>
<td>100%</td>
<td>89%</td>
<td>131%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>165%</td>
<td>136%</td>
</tr>
</tbody>
</table>

Table 6.11: Percentage comparison for Heerhugowaard.

<table>
<thead>
<tr>
<th>Purmerend</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash risk</td>
<td>100%</td>
<td>0%</td>
<td>85%</td>
</tr>
<tr>
<td>Fatality risk</td>
<td>100%</td>
<td>143%</td>
<td>43%</td>
</tr>
<tr>
<td>Waiting time car</td>
<td>100%</td>
<td>83%</td>
<td>93%</td>
</tr>
<tr>
<td>Waiting time bike</td>
<td>100%</td>
<td>110%</td>
<td>0%</td>
</tr>
<tr>
<td>Emission of CO$_2$</td>
<td>100%</td>
<td>96%</td>
<td>141%</td>
</tr>
<tr>
<td>Emission of Pm$_{10}$</td>
<td>100%</td>
<td>86%</td>
<td>141%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>86%</td>
<td>84%</td>
</tr>
</tbody>
</table>

Table 6.12: Percentage comparison for Purmerend.

For each criteria goes, the lower the percentage the better. Next to that, each criteria is valued equally in this comparison. Taking this into account, a total percentage can be calculated, being the average of the individual criteria.

When looking at these totals, one can see that based on all criteria, the pleintje ranks best in Heerhugowaard, followed by the roundabout and priority intersection scoring the worst. In Purmerend, almost the exact opposite is the truth, with the roundabout ranking best, closely followed by the priority intersection and finally the pleintje.

6.4.2 Monetary comparison

Whereas the first comparison ranks the different intersections based on equal criteria, the next comparison attempts to rate each criteria with a different monetary value. These monetary values are based on the CBA indicators as used by Rijkswaterstaat. These indicators are used by Rijkswaterstaat to perform Cost Benefit Analysis for new infrastructure and are based on different studies for different indicators. For example, SWOV fact sheets for traffic safety indicators and studies of CE Delft for indicators on the environment. This way, each parameter is given a certain weight to it, based on the CBA indicators. It would also give an indication to what is valued more important, for example safety could be more important compared to the emission of CO$_2$. However, in order to be able to use these parameters, two assumptions have to be made.
The first is the value of time, needed to value the waiting times. The study only gives a value for motorized travel time, not for cyclists, as it can be understood that cyclists (short travel distances) value their time differently compared to car drivers (longer travel distances). For the sake of comparison, both the car and cyclists value of time is rated at the same value as no specific bicycle value of time is available.

Second, the safety indicators give values for a traffic fatality or injury. However, this research is not based on actual crashes, but only on conflict observation, or ‘near-crashes’, as well as a fatality risk based on speed measurements. In order to be able to use the indicators, the critical conflict or crash risk parameter, has to be transformed into a crash parameter. As there are no direct conflict to crash formulas as mentioned earlier, an assumption will be made. In this case, the crash data for the respective intersections has been analyzed giving a certain number of crashes involving cyclists over a period of ten years. These values have been compared with the number of critical conflicts observed. This way, a variable has been found for these situations with which the number of conflicts are multiplied to get an estimate for the number of crashes. For this study this parameter was found to be 0.00454, meaning the number of observed critical conflicts has to be multiplied by this variable to get an estimate for the number of crashes.

In order to make a difference between traffic fatalities and injuries, the fatality risk is used. This means that based on the number of crashes, a certain percent results in a fatality, while the rest is considered to be an injury. This way, the conflict observations as well as the speed measurement are converted into crash data, divided into traffic fatalities and injuries. Two parameters which can be expressed in a monetary value using the safety indicators listed below.

With these assumptions in mind, the monetary values based on the Rijkswaterstaat CBA indicators and used for this comparison are as follows.

Traffic safety, cost of a life: €2,744,541 per life.
Traffic safety, cost of a serious injury: €282,164 per injury.
Traffic flow, value of time for a car: €10.67 per hour.
Traffic flow, value of time for a bike: €10.67 per hour.
Environment, cost of CO₂: €62.66 per ton.
Environment, cost of PM₁₀: €376.91 per kg.

Using these indicators and the earlier displayed results, a monetary comparison for both Heerhugowaard and Purmerend can be made. The results are listed in the two tables below.
A comparison between the pleintje, priority intersection & roundabout

<table>
<thead>
<tr>
<th>Heerhugowaard</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic fatalities</td>
<td>€0.0041</td>
<td>€0.0223</td>
<td>€0.0048</td>
</tr>
<tr>
<td>Serious injuries</td>
<td>€0.0043</td>
<td>€0.0206</td>
<td>€0.0161</td>
</tr>
<tr>
<td>Value of time, car</td>
<td>€0.0107</td>
<td>€0.0098</td>
<td>€0.0190</td>
</tr>
<tr>
<td>Value of time, bike</td>
<td>€0.0107</td>
<td>€0.0124</td>
<td>€0</td>
</tr>
<tr>
<td>Cost of CO₂</td>
<td>€0.0047</td>
<td>€0.0043</td>
<td>€0.0061</td>
</tr>
<tr>
<td>Cost of PM₁₀</td>
<td>€0.0333</td>
<td>€0.0297</td>
<td>€0.0436</td>
</tr>
<tr>
<td>Total</td>
<td>€0.0678</td>
<td>€0.0991</td>
<td>€0.0896</td>
</tr>
</tbody>
</table>

Table 6.13: Monetary comparison for Heerhugowaard.

<table>
<thead>
<tr>
<th>Purmerend</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic fatalities</td>
<td>€0.0130</td>
<td>€0</td>
<td>€0.0047</td>
</tr>
<tr>
<td>Serious injuries</td>
<td>€0.0178</td>
<td>€0</td>
<td>€0.0158</td>
</tr>
<tr>
<td>Value of time, car</td>
<td>€0.0086</td>
<td>€0.0071</td>
<td>€0.0080</td>
</tr>
<tr>
<td>Value of time, bike</td>
<td>€0.0092</td>
<td>€0.0101</td>
<td>€0</td>
</tr>
<tr>
<td>Cost of CO₂</td>
<td>€0.0035</td>
<td>€0.0033</td>
<td>€0.0049</td>
</tr>
<tr>
<td>Cost of PM₁₀</td>
<td>€0.0503</td>
<td>€0.0433</td>
<td>€0.0711</td>
</tr>
<tr>
<td>Total</td>
<td>€0.1024</td>
<td>€0.0638</td>
<td>€0.1045</td>
</tr>
</tbody>
</table>

Table 6.14: Monetary comparison for Purmerend.

Since all of these values are costs (to society), they can be all compounded to get a total value for the intersections.

Most interesting fact is perhaps the 'big' difference between Heerhugowaard and Purmerend. The roundabout gives somewhat the same results for both cities, but both the pleintje and the priority intersection vary quite a bit between the two cities. In Heerhugowaard the pleintje scores best, while it scores much worse in Purmerend. For the priority intersection this is the opposite. Looking at the numbers, the main cause for this are the traffic safety values, which vary quite a bit between both cities. Other parameters, as well as the traffic safety values for the roundabout are more or less equal when comparing the results for both cities.

Final words for chapter six

Chapter six has given a comparison between the intersections. At first for each individual aspect, traffic safety, traffic flow and environment. Finally, all these individual aspects are combined to make a total comparison between the intersections taking all criteria into account. What could be seen though is that there is no clear relation between the scores of Heerhugowaard and Purmerend. Results vary quite a bit, so no definite conclusion can be made if one type scores better than the other. Before these results are used to make any conclusions and recommendations, as well as answer the research questions, an evaluation of the project will be given in the next chapter. Focusing on what (possibly) went wrong during this study, mainly during the data collection and data analysis steps. And more important, how does this influence this study and the results.
Chapter seven gives an evaluation of the project, as well as possible errors in the data collection and analysis.

7.1 General evaluation of the project

In general, the project went mostly as planned. The main setback, if one could call it that way, is the time it took to analyze all the video data. This took quite a bit longer than expected, setting the planned schedule back a few weeks. Apart from this, most other aspects of the project went as planned. Even the camera observations itself went without any problems, with both municipalities willing to cooperate, as well as good conditions during the observations itself.

Finally, it has to be taken into account that the result of this study is only based on a limited set of intersections. Two pleintjes, two priority intersections and two roundabouts. It could well be that the two pleintjes observed are two outliers compared to other pleintjes. The same can be said about the other two intersections as well, even though those results can also be backed up by other studies performed.

This does however mean, that any conclusion made in this study can not be seen as a general conclusion which goes for all intersections of these types. In principle, this study should be seen as a manual for which further research can be done on both the pleintje as well as the roundabout and priority intersection and how to compare them with each other.
7.2 Possible errors in data collection

As mentioned in the previous paragraph, the camera observations went without much problems. Weather conditions were good in general. Although there have been some small differences in weather conditions. The first two observations were during bright sunny days, while the others were during cloudy days, with the last even giving a bit of drizzle during the day. This may have had some effect on traffic, possibly less cyclists due to the drizzle compared to the sunny conditions.

Next to this, the camera set-up was not placed at equal distances at all intersections. Due to possible placement, some observation were made a little closer to the intersection compared to others. The same goes for the possibility in noticing the measurement truck, which differed slightly from intersection to intersection. Although the truck itself was rather visible on most intersections. This does mean there is a possible influence of the truck to the traffic. This was also seen during the analysis, with cars suddenly braking without any real reasons to do so, apart from the fact that they may think the observation was for a speed control.

Last but not least, two of the observations were done during a holiday period, while the other four where not. Even though this was unavoidable due to the restricted availability of the measurement truck, it may have caused differences in traffic patterns and behaviour. For example, less traffic during the rush hour, but more traffic during the day, as people get up later during a holiday period. Or less traffic in general as people do not have to travel to work or school and just stay at home.

Both the differences in weather condition, holiday period, as well as measurement set-up may have resulted in minor differences in the data which aren’t caused by the intersection itself, but by these other factors.

Another major issue was the fact that part of the priority intersection data for Purmerend was lost. Not only this, but the traffic intensities also appeared to be lower than expected compared to the other two intersection in Purmerend. Taking both of these issues into account, the data used in the comparison could be questionable.

For this study it means that the data from the Purmerend priority intersection is highly questionable and possibly unusable. Not so much for the speed measurement, as still plenty of cars have been measured with the still available video material. With the conflict observation, things are a bit worse. Due to the lower intensity, as well as missing footage, not a single critical conflict was observed. This means that the priority intersection in Purmerend would rate as being completely safe, as nothing appears to happen. Obviously this does make it hard to compare it to the pleintje and roundabout and even more difficult to make any proper conclusions. One may even go as far as to say its best to exclude the priority intersection, or only focus on the parameters that do have reliable data, thus ignoring the conflict observation for the Purmerend priority intersection.
Next to the observations, there are also some possible errors with the simulations, mainly due to the program restrictions. For example, the fact that cyclists do not travel against driving direction in the program, while they quite obviously do in reality. Other 'illegal' behaviour, like cutting corners or crossing where they are not meant to, are not simulated by the program. The same also applies for the geometry of the intersections. The program only allows for a set number of standard intersections to be selected. Even though different dimensions can be given, it cannot handle intersections which are different from the standard. This was mainly the case for the Heerhugowaard priority intersection, as its design was different from the standard designs given in the program (dual lanes).

All these differences, both the deviation from the standard designs, as well as the behaviour factors like that of cyclists, do influence the results that are provided by the simulations program. Due to these differences, it is likely that the results are also different from the real values. For this study however, no real values have been measured, so it is unknown if this difference is significant or not.

Last but not least, a simulation program is just that. It is only an attempt to recreate reality, even though a good one, but it is not guaranteed the same as the reality. Therefore, the results may differ from the actual real world counterparts.

### 7.3 Possible errors in data analysis

When reviewing the data, several problems occurred while reviewing the video images. As mentioned earlier, certain camera angles sometimes had trouble with light reflecting of the road or buildings. This caused for certain parts of the film to be difficult to see. Conflict observation was still able to be performed, but the speed measurement was more difficult because of this. The recognition points were sometimes quite difficult to see, making it harder to properly time the cars and measure their speed accordingly.

Next to light reflecting into the camera, certain objects sometimes blocked the view as well. Mainly, trees and bushes which sometimes made it hard to see the recognition points for the speed measurements as well as the conflict observation. For the conflict observation, the view was sometimes blocked by a large vehicle like a bus or a truck. In these cases, encounters were counted, but it was not possible to see if they were a (critical) conflict or not, so they may have been missed because of it.

The speed measurement was also done manually. This involved pausing the video whenever a car passed the recognition point and note the time. Even though the time was given in hundreds of seconds, it is impossible to time each car at each point that accurately and may have small errors in them because of this.

Last but not least, the human imperfection. Even though most of the analysis has been done with the utmost precision and care, it is easy to make a mistake. A simple error in one of the Excel sheets, or a missed (critical) conflict while reviewing many of the hours of video material. A mistake is quickly made, but hard to find.

Finally, all these possible errors may lead to little errors in the final data and analysis. However, since most of these possible errors are equal for all intersections due to the manual processing, the consequences are most likely not that large. And due to the large number of speed measurements, both upwards and downwards, errors could be averaged out in the end values.
Final words for chapter seven
The past chapter provided an overview of possible errors made during this study, mainly during the data collection and analysis steps. In general though, most of these errors are not likely to cause any major flaws in the results. There is one exception though, the missing data from the priority intersection in Purmerend in combination with the lower traffic volumes. This makes the conflict observation data from this intersection hardly usable in any kind of comparison. Mainly since there have been no critical conflicts, ranking this intersection as very safe using this research method. Even though there are some minor errors, as well as a more severe one, it is possibly to draw some conclusions as well as make recommendations. And also give an answer to the research questions stated in chapter two. The final chapter will therefore give an answer to these questions as well as give the conclusions and recommendation based on the results from this study.
This final chapter will answer the research questions proposed in the second chapter. Based on these answers, conclusions and recommendations will also be made.

8.1 Answers to the sub research questions

As mentioned in chapter two, a number of sub research questions have been proposed, which were aimed to be answered with this study. This paragraph will answer those questions one by one.

*Which conflicts appear on the pleintje, the priority intersection and the roundabout, between motorized traffic and cyclists?*

The main research goal of this study were the conflicts between crossing cyclists and passing vehicles. So even though there are many other conflicts at the intersections, the main focus has been the conflict between a crossing cyclist and a passing vehicle. Most of these encounters happened without anything noteworthy happening. Some of these encounters were more severe and are considered as a conflict or even a critical conflict when the estimated TTC was small enough.

Looking at the conflicts, several types have been distinguished. First off all the conflicts where both the vehicle as the cyclist makes an evasive manoeuvre. Second, the conflicts where the wrong traffic participant took priority. Third, the conflicts where the wrong traffic participant was given priority. These are the different types of conflicts that were observed. Note, critical conflicts come forth out of this group of conflicts.

When looking closer at the critical conflicts, it could be seen that the conflict where the wrong traffic participant took priority was the main cause. In essence, this makes sense, as it changes the situation completely for both traffic participants. For example, a car takes priority, forcing the cyclist to brake instead of drive on. Reasons why this happens vary from situation to situation, examples being priority situation, driving direction, etc. More about these reasons will be answered in a later sub-question.
Something which is noteworthy is the location where the (critical) conflicts happened. What could be seen during the observations is that for the roundabout and the priority intersection, the majority of the conflicts appeared while cyclist crossed the main road. Even though this was more or less the case with the pleintje in Heerhugowaard as well. In Purmerend this was quite the opposite where all critical conflicts, as well most of the other conflicts appeared when cyclists crossed the side street. Looking even closer to the locations, it could be seen there was hardly any difference between the 'first' or 'second' crossing of the road. Critical conflicts are spread out evenly over both lanes of the road.

*How often do these conflicts appear and how critical are they?*

The number of these encounters and (critical) conflicts have been shown in paragraph 6.1.1, both in absolute measured values as well as divided by the measured intensity and rated alongside each other.

What can be seen from these tables is the fact that in Heerhugowaard, the pleintje is by far the 'best', with critical conflicts appearing to be 3.5 to 5 times as much on the other intersections. More interesting perhaps is the fact that the number of encounters and conflicts are roughly the same, while the number of critical conflicts does differ quite a bit. This could lead to the assumption that if an encounter occurs at the priority intersection or roundabout, there is a bigger chance at a critical conflict when compared to the pleintje.

In Purmerend the number of critical conflicts are a lot more equal, with the roundabout scoring slightly better compared to the pleintje. The priority intersection did not see any critical conflicts in Purmerend, but is best ignored in this comparison due to previously mentioned reasons. When comparing the roundabout and the pleintje though, the same phenomena as in Heerhugowaard occurs. Namely the fact that there seems to be a bigger chance at a critical conflict at the roundabout when an encounter occurs in comparison to the pleintje.

The observation method was also used to categorize the critical conflicts to severity. Based on these results, the critical conflicts on the roundabout were rated slightly lower compared to the ones from the pleintje and the priority intersection. This is mainly because the speed is lower at the roundabout compared to the other intersection types. This make the conflicts less serious, as the result of an actual crash would probably have been less severe as well due to this lower speed.

*What is the speed profile from the pleintje, the priority intersection and the roundabout? Of special interest is the place where the actual conflicts are happening.*

For the six observed intersections the speed was measured at both vulnerable road users crossings, with cars both approaching and leaving the intersection. This was done for both driving directions. The results saw no significant difference in the driving direction. For the priority intersection and pleintje, both the approach and leaving speed were the same as well. Only for the roundabout, the leaving speed was a little higher than the approach speed.
Paragraph 6.1.2 shows a good overview of the average speeds and what this means for the risk of a fatality when a crash happens. Results were much more conclusive compared to the conflicts, with the roundabout measuring the slowest average speeds around 29 km/h. The pleintje and priority intersection did not differ much, although in general the average speed at the pleintje was slightly lower, 45 km/h for the pleintje versus 48 km/h for the priority intersection. Not only the average speed differs, but also the homogeneity of traffic is important. As the roundabout forces all traffic to slow down due to its design, this is less the case for the pleintje and not at all present for the priority intersection. The result is already seen in the average speeds, but it also has an effect of the homogeneity. The variance in speed is the lowest at the roundabouts, followed by the pleintjes and the highest variance was measured at the priority intersections.

What are the speed dynamics of the pleintje, the priority intersection and the roundabout? And what does this mean for the traffic flow and environment?

The speed dynamics in this case, relate to the total accelerating and decelerating that happens at each intersection. One key indicator for this is the number of stops, which give an indication for both traffic flow and environmental issues. More details can be found in paragraphs 6.2 and 6.3. In general it was shown that the roundabout scored worst compared to the other intersections. Emissions values scored 30% to 50% higher compared to the pleintje and the priority intersection. The same results were seen for the traffic flow in Heerhugowaard, where cars had the longest average waiting times at the roundabout (almost twice as long). In Purmerend however, the pleintje was seen to be having the longest average waiting time for cars, even though the differences are a lot smaller compared to Heerhugowaard. Looking at the cyclist waiting time, there is none at the roundabout, as cyclists have right of way on all branches. The pleintje and priority intersection show similar values, with the pleintje having slightly shorter waiting times. Comparing the emission values for the pleintje and the priority intersection, it seems the priority intersection scores slightly better which is quite interesting. Reason for this is the fact that the pleintje was introduced as environmental friendly design, which would lead to the hypothesis that it would perform better than the traditional priority intersection.

Finally, it seems both the traffic flow and environment parameters are not only influenced by the intersection design. Just as with the traffic safety, other factors like priority rules, have a large influence on the results. Giving priority to cyclists reduces their waiting times, but increases car waiting times as a result. Not only this, but the waiting cars also produce more emissions because of the extra accelerating and decelerating. But this is the case when looking at just local intersection. When zooming out a little, giving priority to the cyclist could also lead to less car usage and more bicycle usage instead. This would in return lead to less emissions as there will be less travel by car. However, zooming out like this falls out of the scope of this study, but does show some of the side notes that have to be taken into account with the results of this study. Something what works on a local level, may not work the same when looking at a broader scale.
Are there other specific aspects (intersection design, etc.) that influence the traffic parameters and in what way?

The main influence in speed that appeared during the observation was the intersection design. The roundabout design forced the speed down, while this was (almost) not the case for the pleintje and the priority intersection. This was to be expected, but also showed that the intended design speed of 40 km/h at the pleintje was not reached. In fact, traffic was able to pass at much greater speeds and did so on several occasions.

Another main aspect which greatly influences the traffic parameters are the priority rules. At the roundabout, cyclists have priority at all branches, while for the pleintje and the priority intersection, motorized traffic has priority on the main road. At the pleintje and the priority intersection this results in cyclists waiting for cars to pass, giving cyclists the most responsibility as they have to decide if they can cross or not. What was seen in most situations is that the cyclist indeed notices the car and acts accordingly. If the car drivers also notices the cyclists approaching/waiting could not be seen. Cars would simply continue at the same speed regardless of cyclists waiting/approaching or not. If this is because the car drives simply do not notice the cyclists, or if they do not care could not be discovered.

For the roundabout, the situation is different, as the cyclist has priority over the motorized traffic approaching. This reverses the roles compared to the other two intersection types, as it is not the car drivers who have to decide if it is safe to pass. This seems to be more difficult than the other way around, which showed in the number of (critical) conflicts. Another interesting fact which was observed at the roundabouts, is the fact that cyclists have and take priority, usually not paying attention to any motorized traffic approaching. It seems that their general reasoning is, I have priority, so I will receive it too.

Another aspect which is closely linked to this is the driving direction of cyclists. Even though some of the intersections allowed cyclist to drive in both directions, others did not. In general though, regardless of intersection type, cyclists ignored these rules and just took the shortest route over the intersection. This did cause some additional problems at the roundabout though. As the responsibility for a safe passage lies with the car driver, and they did not always notice cyclists coming from the opposite direction. This resulted in a higher amount of (critical) conflicts involving cyclists driving against the normal direction. This was not the case for the pleintje and the priority intersection. In this case cyclists would also drive against direction, but the responsibility for a safe crossing lies with the cyclist. So regardless of driving direction, they would still have to check for an approaching car. But instead of the roundabout having cyclists approach from two directions, cars only approach from one direction at a time, as they cross each lane individually. Next to that, a cyclists speed is a lot lower compared to a car, making it easier to check if it is safe to cross or not.
The next aspect is the possibility to cross the street which is depended on the down-stream situations, as this determines the way cars appear at the intersection and the gaps between them. On both pleintjes, this effect could be seen rather well. On one side of each pleintje a roundabout was situated, while on the other a signalized intersection/railway crossing was placed. This meant that traffic driving from the roundabout, arrived in a more continues stream compared to the other direction. As from the other side, cars arrived in groups, due to the signalized intersection/railway crossing only allowing a fixed number of cars through at a time. This also made sure there appeared numerous gaps between these groups, which could be used by vulnerable road users to cross. From the other side traffic gaps were less fixed and caused some trouble crossing the street, especially during rush hour.

8.2 Answer to the main research question

Finally, the main research question will be answered in this paragraph.

*How does the traffic safety of the pleintje, priority intersection and roundabout compare with each other?*

Looking at the conflict analysis and the speed measurements, this answer is twofold. On one part there is the risk of a crash based on the conflict observation. On the other, there is the effect if a crash does happen. While the second was rather similar for both occasions, the first is less clear.

First the conflict analysis. In Heerhugowaard, the percentage of critical conflicts are lowest for the pleintje, followed by the roundabout and the priority intersection. In Purmerend the exact opposite holds true. However, when looking deeper into the ratios between number of encounters, conflicts and critical conflicts, it can be seen that for both Heerhugowaard and Purmerend, the number of (critical) conflicts that come forth from the number of encounters is larger for the roundabout compared with the pleintje. This means that the chance at a (critical) conflict, if a cyclist and a car have an encounter, is larger at a roundabout than at a pleintje. The priority intersection still shows no coherent story even looking at these ratios.

Second, the speed measurements give a much clearer picture. The roundabout scores best, with the lowest speed by far, meaning the effects of a possible crash are lowest. The pleintje and priority intersection don’t differ much, even though the pleintje ranks better, with a slightly lower average speed.

So what would this mean the crash risk (conflicts) and the fatality risk (speed)? The occurrence of an encounter gives no clear picture based on these two cases, with both giving different. It does show that if an encounter occurs, the chance at a critical conflict is highest at the roundabout, while lowest at the pleintje. However, the speed at the roundabout is by far the lowest when compared to the other two intersection. So it seems the intersections either have a high crash risk or a high fatality risk.
But what does this mean for the traffic safety in general when taking both the risk and
effects into account. Best way to look at this, is to use the monetary comparison,
where both the risk and the effects were taken into account and expressed in a
monetary value. Table 8.1 and Table 8.2 give an overview of the average traffic
safety costs, taking all aspects for both locations into account.

<table>
<thead>
<tr>
<th>Heerhugowaard</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic fatalities</td>
<td>€0.0041</td>
<td>€0.0223</td>
<td>€0.0048</td>
</tr>
<tr>
<td>Serious injuries</td>
<td>€0.0043</td>
<td>€0.0206</td>
<td>€0.0161</td>
</tr>
</tbody>
</table>

Table 8.1: Traffic safety value for Heerhugowaard.

<table>
<thead>
<tr>
<th>Purmerend</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic fatalities</td>
<td>€0.0130</td>
<td>€0.0000</td>
<td>€0.0047</td>
</tr>
<tr>
<td>Serious injuries</td>
<td>€0.0178</td>
<td>€0.0000</td>
<td>€0.0158</td>
</tr>
</tbody>
</table>

Table 8.2: Traffic safety values for Purmerend.

The most interesting aspect which is shown by this table is the fact that there is no
clear answer based on these two cases. Even though the result for the roundabout is
quite similar in both cities, the results for both the pleintje and the priority intersection
are rather different.

Another aspect which catches attention is the difference between the traffic fatality
value and the serious injury value. Regardless of the actual value and the city, it
seems that these values are more or less equal when looking at the pleintje and the
priority intersection. For the roundabout however, this is not true, as the value for
serious injuries is significantly higher compared to the value for traffic fatalities.

But what does this all mean for the safety of the three intersections studied? Based
on the observed intersections, no safest design can be pointed out yet. Reason for
this is that the results show a large variation. Something which does appear to hold
true, is the fact that the consequences of a possible crash appear lowest on the
roundabout. Something which comes to no real surprise, as the speed is lowest.

8.3 Conclusions

In general, a few conclusions can be made based on this study. However, any con-
clusion made should only be seen as a first guideline for further research. Since only
two of each intersections have been measured, results and conclusions are rather
location specific and may not be representing a general conclusion. Taking this into
account, these are the conclusions based on the six observed intersections.

The pleintje shows the lowest crash risk based on the conflict observation. Based on
the number of encounters, as well as the number of conflicts and critical conflicts, the
chance of a (critical) conflict is the lowest. This is mainly based on the fact that if an
encounter occurs, the chance at a (critical) conflict appears larger for the priority
intersection and the roundabout.
However, the fatality risk if a crash does happen, is lowest at the roundabout. The pleintjes fatality risk is two to three times higher due to the higher speed, while the fatality risk for the priority intersection is even slightly higher. Bottom line, the crash risk is lowest at the pleintje, while the fatality risk is lowest at the roundabout. Taking both risks into account, no clear result was found if one weighs heavier than the other, as there are mixed results when comparing both cities. The priority intersection does look to be a bad solution all around with a high crash risk and a high fatality risk as well.

The traffic flow is divided into two groups, cars and cyclists. The traffic flow for cars appears to be best at the priority intersection, while they are worst at the roundabout. For cyclists, the roundabout is best, with the pleintje and priority rating more or less the same.

Environmental aspects are in favour of the priority intersection, ranking best. The pleintje scores slightly worse, while the roundabout is significantly worse when it comes to emissions.

Finally the total results for both absolute and the monetary comparison are show in Table 8.3 and Table 8.4 which shows these values for both Heerhugowaard and Purmerend.

<table>
<thead>
<tr>
<th>Heerhugowaard</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage</td>
<td>100%</td>
<td>165%</td>
<td>136%</td>
</tr>
<tr>
<td>Monetary</td>
<td>€0.0678</td>
<td>€0.0991</td>
<td>€0.0896</td>
</tr>
</tbody>
</table>

Table 8.3: Values total comparisons Heerhugowaard.

<table>
<thead>
<tr>
<th>Purmerend</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage</td>
<td>100%</td>
<td>86%</td>
<td>84%</td>
</tr>
<tr>
<td>Monetary</td>
<td>€0.1024</td>
<td>€0.0638</td>
<td>€0.1045</td>
</tr>
</tbody>
</table>

Table 8.4: Values total comparisons Purmerend.

Most interesting fact shown in these tables, are the differences between the two cities. There is no clear 'winner' or 'loser', as values differ per intersection design and per city as well. However, this has always been the case with this study. Due to the low number of intersections observed, it was almost impossible to find any conclusive results. It does give a good overview of the possibilities for further studies into this field, using the methods described in this study.
Finally, there is a final note that has to be made, namely the priority rules. Most of the parameters used in this study are not only influenced by the intersection type, but also by the priority rules that are used at the intersection. For the roundabout cyclists have priority. This results in lower waiting times for cyclists, but longer waiting times for cars, as they have to wait. If they have to wait, this comes due to them braking for a crossing cyclist. More braking and accelerating also means more emissions. This line of reasoning also holds true for the results in the comparison for the intersections. Therefore, it may not only be the question of which intersection design is best, but even more which priority rules are best.

8.4 Recommendations

As mentioned earlier, this study has its limitations. Mainly being based on only a very limited number of intersections that have been observed. Therefore, this study could better be seen as a first guideline for following studies. Based on the results and conclusions, here are some recommendations for possible next steps. Next to recommendations for future studies, there are also a few recommendations which may be applied in practice based on the results of this study.

Observe more pleintjes and intersections
Quite obvious, but observing and evaluating more intersections and pleintjes in special, would be a logical next step. Since only two of each intersection have been studied, the results are rather location specific and may be completely different at other locations. Studying other intersections should give more insight and provide an answer if the results found in this study hold true or not.

Accurate speed measurement
The method used for measuring the speed is not the most accurate around. The best method to use is most likely by using a laser gun. This would provide quick and accurate data about the speed at a fixed location.

Measurements for traffic flow
Traffic flow parameters have been simulated for this study. However, if the simulated results are similar to the real world situation has not been verified yet, not for the pleintje at least. Average waiting times could even be calculated with the help of the video images used in this study, simply by timing the waiting times for cyclists before they are able to cross. The same could be done for cars, measuring their travel time and compare this to unhindered travel time across the intersection. The extra time needed is their time loss due to passing the intersection.

Measurements for emissions
As with the traffic flow parameters, emission values have only be simulated. If they are similar to the real world situation have not been verified yet, not for the pleintje at least.
Influence of priority
The influence of the chosen priority rules may be a lot bigger than the actual choice of intersection design. As pointed out, the priority for cyclist may have quite some effect on other traffic parameters used in this study. Ideally, future studies also focus on roundabouts without cyclists having priority and priority intersections and pleintjes with cyclists having priority. This could show if the results found in this report are more a result of the priority rules or the intersection design itself. One problem though as pleintjes are naturally designed with cyclists having no priority. So performing a study on a pleintje with cyclists having priority is highly unlikely to take place. However, roundabouts without cyclists having priority are available, so they could be used to at least get a partial answer to this question.

Influence of network relations and effects
Another aspect that was seen is that the functioning of an intersection is not only depended on the intersection itself, but also its place in the network and the design of the network. The available gaps for crossing traffic are not based on the intersection design, but more on the downstream design. If there is a roundabout or a signalized intersection has quite an effect on the arriving traffic and available gaps. Not only this, but there are also other influences between adjacent intersections. In Heerhugowaard for example, both the pleintje and the roundabout were situated next to each other. Something which was observed was that cyclists would choose a route allowing them to cross at the roundabout instead of the pleintje (some were also seen doing the opposite, although less in number). In general, this also means that an intersection is affected by its neighbours in multiple ways. Even though this study has compared intersections at an individual level, it can not be denied that there are certain relations that influence the results. Further research could investigate these influences.

More speed reduction in design
The speed measurements taken from the pleintje show a clear picture about the average speed, but also the maximum speed which is possible. As the original idea of the pleintje (and Largas), was to reduce the speed to 40 km/h, it can be seen that this idea is not realized. Both in Purmerend and Heerhugowaard, average speeds are (slightly) above this 40 km/h goal. However, maximum speeds show even larger values reaching 60-70 km/h (at the roundabout for example, it is quite difficult to pass at a speed over 40 km/h). Based on this, it would seem the design of the pleintje could use some more work in order to reduce the speed even more. Or at the very least, reduce the maximum speeds which have been measured.

Rumble strip
Something which may be linked to this speed issue, is the fact that the applied rumble strips in Heerhugowaard did not seem to work at all. In fact, the rumble strip was used more than the regular asphalt. Even though this was mainly the case on the centre island and the left turning lanes, it was also seen by cars continuing over the main road, cutting the corner over the rumble strip. Making the rumble strips more rough would prevent the use of these strips to cut corners.
Centre island
The functioning of the centre island of the pleintje is key to its design. Separating both left turning movements makes the traffic flow much smoother. This was exactly the case in Heerhugowaard, which made the pleintje work as intended. However, in Purmerend, this was not entirely the case, as part of both left turning lanes occupied the same space. This led to some conflicts as well as spillback onto the main road. Hence the recommendation that a pleintje works best with a proper centre island and separated left turning lanes.

Priority rules
An point of interest are the priority rules and the ongoing discussion if cyclists should receive priority or not. Even though this study is not able to give a final answer about this, it did show that both option have clear advantages and disadvantages. It basically comes down to what argument weighs heaviest. Does one want waiting times for cyclists or waiting times for cars, more global emissions (less cyclists) or more local emissions (waiting cars), responsibility for safety with the car driver or responsibility for safety with the cyclist.

Cyclist driving direction
Something which clearly showed with the roundabout, is the influence of cyclists driving against the regular driving direction. Car drivers did not always notice these cyclists, which led to a conflict. The fact that this showed most at the roundabout, was because the cyclist had priority here. At the pleintje and the priority intersection this was not the case. The reason this difference matters, lies in the fact who is responsible. If a cyclists has priority, the car has to watch out. When a car has priority, the cyclist has to watch out. It seems that if the cyclist has priority it is difficult for a car driver to watch out for cyclists coming from both directions. It is easier for a slower driving cyclist, to watch out for a car coming from one direction (crossing one lane at a time). Therefore, the combination of cyclist priority and driving in two directions is something which should be avoided if possible, as it makes the driving task a lot difficult. Even the reduced speed at a roundabout doesn't change this fact, let alone for pleintjes and priority intersection where speeds are even higher. So the choice for cyclists giving priority to cars on the main road at the pleintje is a sensible one in light of safety. In this case, it does not even matter if cyclists are allowed to drive in two directions or not, as they have to decide themselves if they can cross, having to check in only one direction if a gap is available.


A comparison between the plenitude, priority intersection & roundabout


Other

maps.google.nl for map data.
www.bing.com/maps for map data.
www.cbs.nl for crash data.
www.ce.nl for emission data.
www.rijkswaterstaat.nl for CBA indicators.
www.swov.nl for crash data (BRON).
Appendix A

This appendix gives an example of the speed measurement method which has been used. In figure A.1 an overview is given from the pleintje in Heerhugowaard. It also shows three recognition points, T1, T2 and T3. Whenever a car passes one of these points the time was noted. In the end, the difference between T2 and T1, as well as between T3 and T2 were calculated.

At the same time, distance D1 and D2 are also measured. This way, it is possible to calculate the average speed over D1 and D2 by dividing this measured distance by the calculated time.

All other speeds have been determined using the same method.

Figure A.1: Speed measurement at the pleintje in Heerhugowaard.
Appendix B

As mentioned in the 6th chapter, a few steps have been taken in order to compare the encounter and conflict values for each intersection. This appendix gives an overview of these steps.

The first two tables give an overview of the total number of encounters, conflicts and critical conflicts for both Heerhugowaard and Purmerend.

<table>
<thead>
<tr>
<th>Heerhugowaard</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encounters</td>
<td>289</td>
<td>411</td>
<td>525</td>
</tr>
<tr>
<td>Conflicts</td>
<td>16</td>
<td>14</td>
<td>44</td>
</tr>
<tr>
<td>Critical Conflicts</td>
<td>1</td>
<td>6</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Purmerend</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encounters</td>
<td>271</td>
<td>63</td>
<td>288</td>
</tr>
<tr>
<td>Conflicts</td>
<td>15</td>
<td>2</td>
<td>32</td>
</tr>
<tr>
<td>Critical Conflicts</td>
<td>2</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

The following two tables give an overview of the car and bike intensities for each intersection in both Heerhugowaard and Purmerend.

<table>
<thead>
<tr>
<th>Heerhugowaard</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars</td>
<td>1468</td>
<td>1364</td>
<td>1470</td>
</tr>
<tr>
<td>Bikes</td>
<td>186</td>
<td>246</td>
<td>368</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Purmerend</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars</td>
<td>1136</td>
<td>604</td>
<td>906</td>
</tr>
<tr>
<td>Bikes</td>
<td>118</td>
<td>92</td>
<td>348</td>
</tr>
</tbody>
</table>

Finally, in order to be able to compare the intersections, the number of encounters and (critical) conflicts are divided by the product of the car and bike intensities. This results in the following tables for Heerhugowaard and Purmerend.

<table>
<thead>
<tr>
<th>Heerhugowaard</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encounters</td>
<td>0.001058</td>
<td>0.001225</td>
<td>0.000970</td>
</tr>
<tr>
<td>Conflicts</td>
<td>0.000059</td>
<td>0.000042</td>
<td>0.000081</td>
</tr>
<tr>
<td>Critical Conflicts</td>
<td>0.000004</td>
<td>0.000018</td>
<td>0.000013</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Purmerend</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encounters</td>
<td>0.002022</td>
<td>0.001133</td>
<td>0.000913</td>
</tr>
<tr>
<td>Conflicts</td>
<td>0.000112</td>
<td>0.000036</td>
<td>0.000101</td>
</tr>
<tr>
<td>Critical Conflicts</td>
<td>0.000015</td>
<td>0</td>
<td>0.000013</td>
</tr>
</tbody>
</table>
And finally the step where these values are given as a percentage with the pleintje values set at 100%.

<table>
<thead>
<tr>
<th>Heerhugowaard</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encounters</td>
<td>100%</td>
<td>116%</td>
<td>92%</td>
</tr>
<tr>
<td>Conflicts</td>
<td>100%</td>
<td>71%</td>
<td>139%</td>
</tr>
<tr>
<td>Critical Conflicts</td>
<td>100%</td>
<td>488%</td>
<td>353%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Purmerend</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encounters</td>
<td>100%</td>
<td>56%</td>
<td>45%</td>
</tr>
<tr>
<td>Conflicts</td>
<td>100%</td>
<td>32%</td>
<td>91%</td>
</tr>
<tr>
<td>Critical Conflicts</td>
<td>100%</td>
<td>0%</td>
<td>85%</td>
</tr>
</tbody>
</table>

Next to the above used method of dividing the number of encounters by the product of the bike and car intensities, some researches divide this number not by the product, but by the sum of the bike and car intensities. If this is done here, the following two tables are the result.

<table>
<thead>
<tr>
<th>Heerhugowaard</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encounters</td>
<td>0.17473</td>
<td>0.25528</td>
<td>0.28564</td>
</tr>
<tr>
<td>Conflicts</td>
<td>0.00967</td>
<td>0.00870</td>
<td>0.02394</td>
</tr>
<tr>
<td>Critical Conflicts</td>
<td>0.00060</td>
<td>0.00373</td>
<td>0.00381</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Purmerend</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encounters</td>
<td>0.21611</td>
<td>0.09052</td>
<td>0.22967</td>
</tr>
<tr>
<td>Conflicts</td>
<td>0.01196</td>
<td>0.00287</td>
<td>0.02552</td>
</tr>
<tr>
<td>Critical Conflicts</td>
<td>0.00159</td>
<td>0</td>
<td>0.00319</td>
</tr>
</tbody>
</table>

And again the step where these values are given as a percentage with the pleintje values set at 100%.

<table>
<thead>
<tr>
<th>Heerhugowaard</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encounters</td>
<td>100%</td>
<td>146%</td>
<td>163%</td>
</tr>
<tr>
<td>Conflicts</td>
<td>100%</td>
<td>90%</td>
<td>247%</td>
</tr>
<tr>
<td>Critical Conflicts</td>
<td>100%</td>
<td>617%</td>
<td>630%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Purmerend</th>
<th>Pleintje</th>
<th>Priority intersection</th>
<th>Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encounters</td>
<td>100%</td>
<td>42%</td>
<td>106%</td>
</tr>
<tr>
<td>Conflicts</td>
<td>100%</td>
<td>24%</td>
<td>213%</td>
</tr>
<tr>
<td>Critical Conflicts</td>
<td>100%</td>
<td>0%</td>
<td>200%</td>
</tr>
</tbody>
</table>

All in all, the main difference between the product and sum method is that the absolute differences in value become bigger. In general, when the number of encounters on the roundabout was larger with the product method, the same is found with the
sum method, with the only difference that the absolute difference between the two has become bigger.
The only main value which differs per method are the roundabout values for the Purmerend situation. When using the product method, the roundabout scores slightly better compared to the pleintje. However, when using the sum method, the roundabout is suddenly twice as bad as the pleintje. This difference is most likely caused by the relative high amount of cyclists travelling over the roundabout compared to the other observed intersections.
Appendix C

This appendix gives the large map overview for the six intersections. All images are taken from Bing Maps, showing the current intersections as observed. There is however one exception, the pleintje in Purmerend. This still shows the old situation as the images are slightly outdated, but does give a good picture of the surrounding area. A red circle shows the intersection itself. The intersections are shown in this order.

- Pleintje Heerhugowaard
- Priority intersection Heerhugowaard
- Roundabout Heerhugowaard
- Pleintje Purmerend
- Priority intersection Purmerend
- Roundabout Purmerend
A comparison between the pleintje, priority intersection & roundabout
A comparison between the pleintje, priority intersection & roundabout

Roundabout Heerhugowaard

Pleintje in Purmerend
A comparison between the pleintje, priority intersection & roundabout
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