Complexity at intersections and bicycle crashes

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Preface

On the 22nd of July 2013 I suffered a heavy bicycle crash in the south of France, near Venosc. Immediately a lot of strangers were there to help me. Laying in the hospital I realized that I wanted to do something for other people who suffered bicycle crashes. Or even better prevent bicycle crashes from happening. When I started searching for a Bachelor assignment and realized I could do a research within the traffic safety I knew this was my opportunity. After discussing the possibilities with Karts Geurs, he pointed me in the direction of the SWOV. After a meeting in The Hague it was clear that I wanted to do a research with bicycle safety and intersections. This research is specialized into the relation between complexities at intersections and the amount of bicycle crashes.

Although I did the main part of the research myself, I could not have done this without the help of some other people. Therefor I would like to thank everyone that helped me during the research. Some persons do deserve a special thanks. First and foremost, my supervisor at the SWOV: Gert Jan Wijlhuizen. He introduced me to the subject and company, made me feel at home from day one and helped me whenever I needed his supervision for the assignment. As well as supporting me with feedback and useful sources for my research. Secondly, I would like to thank my supervisor from the UT: Lissy La Paix Puello. She also helped me with literature and advice about the report as well as how to handle the assignment that it would fit within the university. And gave me useful feedback until the last day of the assignment. Some other people at SWOV have helped me, who also deserve a special mention. Firstly Atze Dijkstra, introduced me to the methods and could tell me everything about them whenever something was unclear for me, and gave some useful reports about the methods. Secondly Jan Hendrik van Petegem, who introduced me to the data and explained it very clear for me. And lastly Jacques Commandeur, who helped me very well with the statistics and provided me with literature about the statistics, so I understood what I was doing. In general, I want to thank the fellow interns who I shared a room with and other employees at SWOV who made me feel welcome and made me enjoy my internship from the first till the last day.

Sources illustration front page:
Top: (KWS, 2017)
Bottom: (Beek, 2013)

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Summary

This report is about a research conducted at the institute for road safety research as a Bachelor final assignment. The aim of the research is to find if there is a relation between complexities at intersection and the amount of bicycle crashes. The overall goal is to find specific complexities or characteristics of intersections that influence the amount of bicycle crashes to improve the safety in the future.

The relation between the bicycle crashes and the complexities are conducted with two methods. The first one, conflict points method, focusses on the intersection plane. It counts the number of times two driving lines intersect each other (a conflict point). There will be looked for a relation between the total number of conflict points and bicycle crashes, as well as some special types of conflict points. The second method is the PIARC method, this method focusses on the road sections leading to the intersections just in front of the intersection plane. It determines which characteristics are attendant and gives a total score for the complexities. Between the PIARC score and the amount of bicycle crashes is looked for a relation. Next to the total PIARC score every single characteristic is checked whether they have a relation with the amount of bicycle crashes. The relations are determined with the help of negative binomial distribution models. In each model the traffic flow of the bicycles and cars are taken into account as offset variables, since these also influence the amount of bicycle crashes. Also, other characteristics will be investigated if they have an influence on the amount of bicycle crashes.

The results of the research show that there is no relation between the conflict points and the amount of bicycle crashes. For each of the tested types of conflict points there was no relation found. The PIARC method shows different results. The more complex the intersection is the less bicycle crashes occur. This is substantiated by most of the individual characteristics, they show the same relation. Other characteristics of intersections that were tested show that there is a higher amount of bicycle crashes at 4-way intersections than 3-way intersections.

Based on the results it is advised to add complexities to intersections, especially bicycle facilities, to decrease the number of bicycle crashes at intersection. For future research, it is advised to take a bigger sample of the bicycle crashes by expanding the timeframe when these data were collected or use another source, if this is available, to increase the accuracy. The more accurate data can be used to determine if there is a relation between the insignificant factors and the amount of bicycle crashes or to confirm what was found in this research. Furthermore, it is important to have a good look at the conflict points method, since the results showed no relation where a relation was expected. Also, the mutual relation of complexities and their influence on the amount of bicycle crashes could be investigated in future research.

The conclusion of the research is that there is no relation between the conflict points and the amount of bicycle crashes, but there is a relation between the PIARC method and the amount of bicycle crashes. The more complex an intersection is the less bicycle crashes occur. Probably caused by more complex looking intersections where people pay attention and all the characteristics guide road users over the intersection.

1. Introduction

As a cyclist myself I know how dangerous it can be. Riding your bike through busy cities can be risky. Especially when you cross the street at intersections, I have encountered some close calls or even seen the results of a heavy crash between a car and cyclist. As well as that I know what the consequences of a crash can be. This all has interested me in the question if there are possibilities to improve bicycle safety. The SWOV offers me the opportunity to research a part of the bicycle safety.

1.1. SWOV

The research is done at SWOV (Stichting Wetenschappelijk Onderzoek Verkeersveiligheid/Institute for Road Safety Research), which is a national scientific institute for road safety research. It is their mission to use their knowledge from scientific research to contribute to safer road traffic. SWOV helps answering questions policymakers and other road traffic professionals are confronted with. As a non-profit organization most of the research is made possible by public funds. SWOV works for decentralized and semi-governments. But also consulting firms, companies and international clients use their research experience, such as the European Union. SWOV is independent with respect to its knowledge and research findings. SWOV-knowledge is public knowledge. SWOV develops fact sheets and reports to provide brief, clear and substantiated answers to road safety questions (SWOV, 2019).

1.2. Reason

Many governments are attempting to improve cycling safety to reduce the significant health burden resulting from bicycle crashes and to encourage people to take up cycling since a perceived lack of safety is a deterrent to cycling. The latter is important because regular daily physical exercise through cycling has great health benefits, e.g. Dutch people have half-a-year-longer life expectancy due to cycling. It is therefore important to understand how cycling safety can be improved. (Schepers, Twisk, Fishman, Fyhri, & Jensen, 2017)

Conditions in the Netherlands are conducive to cycling, with a flat terrain, mild climate, high quality bicycle infrastructure, abundant bicycle parking facilities, and short travel distances within cities resulting from high densities and mixed land use. Since 1975 there has been a gradual increase in the distance travelled by bicycle of some 40%. This corresponds to a 20% increase in per capita usage; the other 20% is due to population increase (Schepers, Twisk, Fishman, Fyhri, & Jensen, 2017). A small number of studies have focused specifically on the factors explaining the high level of cycling safety. These suggest that the following policies are critical to the high level of cycling safety in the Netherlands: safe infrastructure (in particular separated cycle paths), traffic calming and intersection treatments, comprehensive traffic education and training of both cyclists and motorists, and traffic regulations that favor cyclist and pedestrians, particularly strict liability. (Schepers, Twisk, Fishman, Fyhri, & Jensen, 2017)

Despite these safety measures and the fact that the Netherlands, together with Denmark, have the lowest fatality rate, per 100 million kilometer, in the world when it comes to cyclist (Pucher & Buehler, 2008), the cycling fatalities increase. Figure 1 shows the development of the amount of traffic casualties (conducted by CBS) in the past ten years, by type of transport. Casualties by car decrease strongly to 187 in 2014, but in 2015 and 2016 increased again. In 2017 it decreased again from 231 in 2016 to 201 in 2017. Also, the pedestrian casualties were slowly decreasing till 2013, but since then they are fluctuating between 50 and 60. For the other types of transport the decrease till 2013 is less clear. For cyclists it seems that there is no case of decrease. Since 2006 the amount of deaths by cyclist was not as high as now (228). In 2017 there are even, for the first time, more people killed riding their bike, than driving their car. (SWOV, 2019)

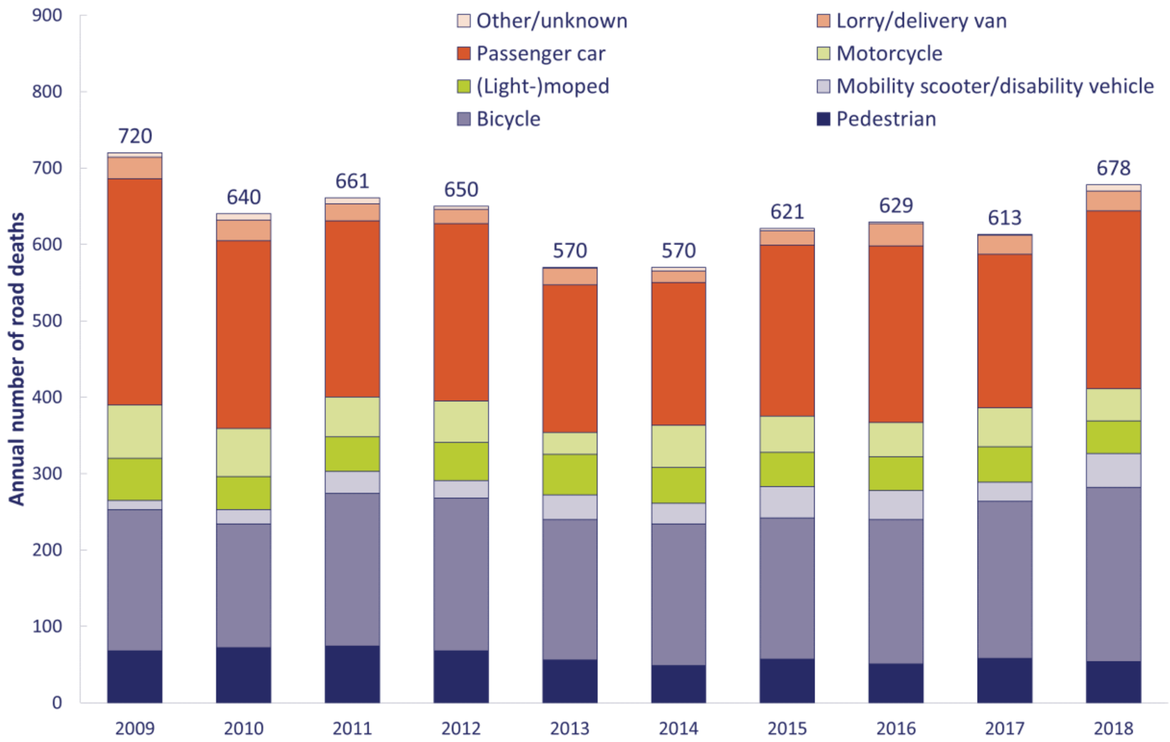

Figure 1: Annual number of road deaths in the Netherlands (SWOV, 2019)

In the past ten years the total amount of annual traffic crashes of all types of vehicles has increased by 2.5%. In 2016 the number of crashes was 21,400; this was the highest since 1993, the start of the registration of crashes (SWOV, 2018). Of the people who are seriously injured 23% have permanent restrictions after the traffic crash. These are long-term consequences mainly due to head injuries, but also to injuries to the lower leg (Slachtofferwijzer, 2018). In 2013 46% of the crashes occurred on an intersection (ANWB, 2013).

Since nearly halve of all the crashes are at intersections a lot of terrain is to win there to improve traffic safety. Therefore, the relation between complexities at an intersection and bicycle crashes will be investigated in this research.

1.3. Aim

The aim of the research is to determine the relationship between the complexities of intersections and the number of bicycle crashes. The focus will be on intersections and bicycles crashes. There will be mainly looked at the number of conflict points of intersections and the characteristics, complexities, of intersections that could affect road safety in combination with the amount of bicycle crashes. The overall goal is to find the complexities that influence the number of bicycle crashes. This to improve the safety in the future.

1.4. Project framework

The SWOV has crash data of intersection in the whole of the Netherlands. This makes it possible to look at all the different types of intersections as well as the location of intersections. Not all the different intersections could be used in this research due to the timeframe of ten weeks. Therefore, a decision is made which types of intersections are used and which are not. Other data needed is the amount of bicycle crashes per intersection.

Amount of bicycle crashes alone will not be enough to get a clear relation between a complexity of an intersection and the amount of bicycle crashes. A second important input will be the traffic flow at the intersections. Since at an intersection with a higher traffic flow it is more likely for bicycle crashes to occur than at an intersection with a low traffic flow. This does not automatically mean that an intersection with a low traffic flow is safer than an intersection with a high traffic flow. There are two types of traffic flow needed, the traffic flow of the cars and the traffic flow of bicyclist.

1.4.1. Relation between complexities and amount of bicycle crashes

The relation will be determined using two methods which will be discussed later in this proposal. One of the methods focusses on the intersection plane. The other method focusses on the characteristics on the road section in front of the intersection.

There could be other design reasons that influence the relation between complexities and bicycle crashes. This and other external factors that could influence the safety will be considered when discussing the results of the research.

1.5. Relevance

As is already explained, the number of bicycle casualties is increasing. One of the possible causes is that it becomes more crowded on the road, creating additional dangers at locations where different traffic users intersect. At intersections there are a lot of conflict points where traffic users cross each other.

Along with the more crowded roads there are other possible causes. For example, the road to an intersection can be unclear, or the driver is unaware that an intersection is coming up. Also, the intersections itself can be built with lots of characteristics, for example public transport lanes, zebra's and traffic signals. These characteristics can influence the safety at intersections causing crashes.

Doing a research to characteristics of an intersections will make it possible to decide which characteristics influence the safety at an intersection. This could mean that in the future it would be advised to (not) use certain characteristic because they have a (strong) negative or positive effect on the safety.

1.6. Structure of the report

In short, the report will look like the following. To start, the research questions will be given with a short explanation. Then the used methods will be described, and an both methods are explained how they are examined with an example intersection. Followed by an explanation of the data and the chosen intersections that are used for this research. Thereafter the results of the sub questions and the main question are given. The report is finalized with a discussion, recommendation and conclusion.

2. Research questions

The main research question for this research is:

What is the relation between complexities at an intersection and the number of bicycle crashes?

This question will be answered with the help of two methods, which will be described in a following chapter, and some sub questions. These sub questions are based on the two methods and the main research question. The sub questions have an explanation how they help answering the main research question.

2.1. Sub question 1

1. *What is the influence of conflict points on the number of bicycle crashes?*

This question will be answered with the help of the first method, the conflict points method. The influence of different types of conflict points will be used to find out if there is a relation and what this relation is. The different types of conflict points are: The total amount of conflict points, the total amount of conflict points involving cyclist and the conflict points between motorized vehicles and bicycles. For these different types of combinations also the conflict points without speed reduction will be determined to see if there is a relation.

2.2. Sub question 2

2. *What is the influence of intersection characteristics on the number of bicycle crashes?*

With the help of the second method, the PIARC method, this sub question can be answered. The PIARC method consists of the three main parts: visibility, entrance speed, road design. These three main parts consist of multiple characteristics which can individually cause a decrease or increase in bicycle safety. The total PIARC score, the three main parts and all the characteristics will be used to find if there is a relation between the characteristics and the bicycle safety. The relation of each characteristic will be research per characteristic, this means that each characteristic is run in the model on their own. The motivation for this is that the influence of each characteristic on their own is researched and not the influence of the different characteristics together on the bicycle safety. Because if all the characteristics would be put together only the characteristics with the strongest influence will be shown as significant characteristics. The individual characteristics are also already tested together in the total PIARC score.

2.3. Sub question 3

3. *Are there other design factors that could influence (severe) bicycle crashes?*

The final sub question discusses if there are other design features, that are noticed during the assessment, but are not taken into account by the used methods. For example, if the intersection has 3 or 4 ways. These design features could influence the results. Also, will be looked at the probability if a (severe) bicycle crash can occur at an intersection based on the Conflict points method, the PIARC method and both methods combined.

3. Methods

The complexity of intersections will be determined by means of two methods. These methods are conflict points and PIARC. These two methods both investigate a different kind of complexity at an intersection. The conflict points method describes the complexity at the intersection plane, where the PIARC method describes the characteristics that you encounter on the road section just in front of the intersection. This is simplified displayed in Figure 2. These methods are chosen because of their simplicity. This makes it possible to assess an abundance of intersection in a short amount of time. Also, the methods are reliable and focus on the design aspects of an intersection. In the chapter 3.5 both methods are explained how they were used in this research and an example with one intersection is given.

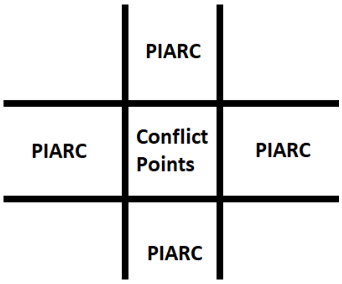

Figure 2: Simplified display of the difference between PIARC and Conflict Points

The results of these methods need to be analyzed to find relations between complexity and bicycle crashes. This will be done with a negative binomial regression model. This method will be explained, and a reason will be given why this method is chosen.

3.1. Conflict points method

The first method that will be applied is the conflict points method. Whether vehicles can collide, and at what angle, depends on the design of the intersection. A roundabout is an intersection type with few conflict points. A four-branch intersection has the most conflict points. As an example, the number of conflict points per intersection type is given for 4-way intersections, 3-way intersections, one-lane roundabouts and bayonet crossings (SWOV, 2015).

As can be seen in Table 1 the amount of conflict points differs per intersection. At most generalized intersection types the traffic must pass a couple of conflict points without obstacles that forces to reduce driving speed below 30 km/hour. The amount of those conflict points without speed reductions are also shown in Table 1. All the amounts of conflict points are related to the 4-way intersection, the intersection with the most conflict points. The amount of conflict points without speed reduction is relatively unfavorable for the 3-branch intersection and the bayonet intersection. This is offset by a relatively small total number of conflict points. The roundabout is in all aspects the best (See also Figure 3) (SWOV, 2014).

Table 1: Conflict points of four simple intersections (SWOV, 2015)

Intersection type	Amount of conflict points			Relative in comparison with a 4-way intersection	
	Total	Without speed reduction	Portion without speed reduction	Amount of conflict points	Without speed reduction
Roundabout	4	0	0	0.17	0
3-way	6	2	0.33	0.25	0.50
4-way	24	4	0.17	1.00	1.00
Bayonet	12	4	0.33	0.50	1.00

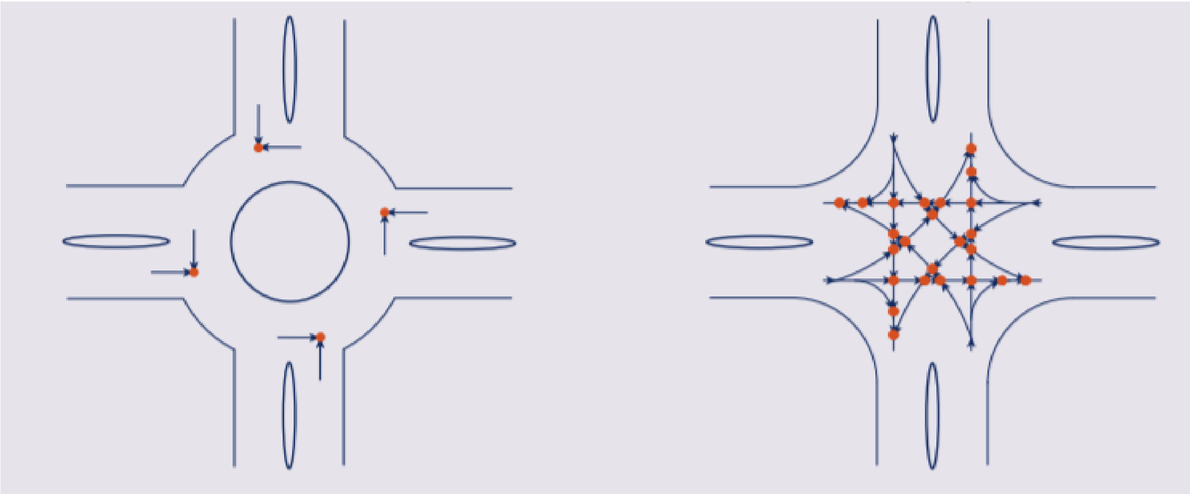

Figure 3: Conflict points of a roundabout and a four-branch intersection (SWOV, 2014)

The expectation of this method is that the higher the traffic flow, the higher the amount of conflict points will be. Also expected is that the number of bicycle crashes increases proportionally with both the number of conflict points and the number of conflict points without speed reduction. Thus, the expectation is, the lower the amount of conflict points the fewer amount of bicycle crashes at an intersection.

3.2. PIARC method

Based on knowledge about human factors, PIARC describes guidelines for assessing safety aspects of intersections, and takes into account the characteristics of the space for the intersection. PIARC distinguishes three general 'safety rules' based on human factors. These three general rules, see numeration below, have been further elaborated in more specific assessment criteria (Table 2).

1. Time needed to respond
    a. Sufficient stop vision
    b. Visibility of critical points
    c. View triangle free from view obstructions
    d. Priority regulation clear
2. Custom speed and lane tracking
    a. No monotonous road or road environment on the approaching road
    b. Sufficient visibility length to avoid critical points
    c. No roadside structures that make lane tracking more difficult
    d. No objects in the roadside that catch the eye and thereby disturb lane tracking
    e. No optical illusions
3. Road design 'steers' the maneuvers of the road user
    a. Use visual cues and eye-catching objects to increase attention and achieve the intended maneuvers
    b. No multiple critical points
    c. Inform road users in time about critical points present
    d. Traffic facilities and traffic signs must match the intersection and road characteristics and the expectations of the road user

(SWOV, 2015)

The assessment of the intersections will be done with the help of Table 2. An intersection will be assessed on the attendance and or the nature of a criterion. Most of the criteria are scored whether they are present or not (score 1 or 0). The lighting can vary between left, right, both sides or in the middle. Scores are respectively 1, 1, 2 and 2. This criterion counts double in the total score because it is applied twice, for both time to respond and adjust speed. The other criteria are graded good, mediocre and bad, scoring 2, 1 and 0. The scores of the characteristics will be added which concludes in a final score for an intersection. An intersection is considered complex when it contains more characteristics. The higher the score, the 'safer' an intersection should be. (SWOV, 2015)

Table 2: PIARC assessment criteria (SWOV, 2015)

Main part	Characteristic	Possible results
Time to respond	Lighting	Left/Right/Both sides/Middle
	Traffic signals	Yes/No
	Speed control	Yes/No
	Signage	Yes/No
	Priority arrangement	Yes/No
	Visibility triangle	Good/Mediocre/Bad
Adjust speed	Distinction hardening	Yes/No
	Lighting	Left/Right/Both sides/Middle
	Direction choice	Yes/No
Steering of maneuvers	Driving direction separation	Yes/No
	Horizontal alignment	Yes/No
	Zebra	Yes/No
	Bicycle facilities	Yes/No
	Field of view	Good/Mediocre/Bad
	Bus/Tram facilities	Yes/No

At first the expectation is that when an intersection has a high score, safer according to the PIARC method, it will have a low number of bicycle crashes and vice versa. But after reading some previous studies this changed. One study showed that when an intersections scores low on the PIARC method (Bad) it also has a low amount of crashes (Good) (SWOV, 2015). Another study shows that the attendance of characteristics reduces the possibility of bicycle crashes (Hamann & Peek-Asa, 2013). This could be caused by people driving more careful when the intersection looks complex. Another reason could be coincidence, due to the small number of intersections used in that previous studies.

3.3. Negative binomial regression model

Regression analyses is a very often used technique. This technique helps to investigate how well a certain factor or variable which we are interested in is predictable out of other characteristics that are measured. With predict it is meant: To what extend says a value of one variable or set of variables something about another variable (Bijleveld & Commandeur, 2017).

A singular regression analysis is about predicting a dependent variable Y from one independent variable X. The used model is $Y = a + bX$. The use of this model implicates that we try to predict the dependent variable Y from one independent variable X. The second implication is that X and Y have a linear correlation. When we make a scatterplot from X and Y the correlation is concluded in one straight line through the point cloud. The formula of this line is the standard like in the regression model. As a matter of course this will not be the case, unless Y is a linear transformation of X. The predictions of Y_i, $\hat{Y}_i$ will be too high or too low. The difference between Y_i and the predicted value of the regression model $\hat{Y}_i$ is the so called prediction error: $e_i = Y_i - \hat{Y}_i$. Which makes the regression equation: $Y_i = a + bX + e_i$. Because e_i is the difference between the prediction and the real Y, the e_i shows how well the regression is doing. If the absolute value of e_i is large, the prediction is far from the real value. If the absolute value of e_i is small, the prediction and the real value are close (Bijleveld & Commandeur, 2017).

The estimation procedure that is used by the regression is the 'least squares' method. If the least squares method is used it says that the regression weight b and the intercept a are calculated in such a way that the summation of the squares of the prediction errors is as small as possible. The equation $\sum_{i=1}^{N} e_i^2$ is minimal. With this method the smallest possible values for a and b are found which makes the estimated values Y_i as close as possible of the real Y_i (Bijleveld & Commandeur, 2017).

The choice for a negative binomial regression model is based on two reasons. Firstly, to analyze data were an assumption of correlation is you use a regression model. To determine what type of regression model exactly will be used is dependent on the characteristics of the data. The goodness of fit of a model should be close to, or below 1. Otherwise you get overdispersion. When you get overdispersion the variability of your data cannot be adequately described by the used model, thus you should use another model in case of overdispersion. When using a Poisson distribution, the mean value is also the median. The negative-binomial distribution is a discrete probability distribution of the number of successes in a sequence of independent and identically Bernoulli trials. In the case of crashes there are often a lot of locations with a few crashes or even none and only a couple of location with more crashes. To make sure that the right type of distribution was used both were tested in SPSS. The test was run with the results of the PIARC method and an offset variable: $\ln(Flow_{Car} * Flow_{Bike})$. The Goodness of fit for the Poisson distribution was 5,945 and the Goodness of fit for the Negative binomial distribution was 0,864. Therefor the negative binomial distribution is the preferred method. To make sure that the right offset variable was chosen, also other possibilities were tested. As can be seen in Table 3 the best offset variable to use is: $\ln(Flow_{Car} * Flow_{Bike})$.

Table 3: Goodness of fit for different offset variables

Offset variable	Goodness of fit
$\ln(Flow_{Car} * Flow_{Bike})$	0.864
$\ln(Flow_{Car} + Flow_{Bike})$	1.488
$\ln(Flow_{Car})$	1.176
$\ln(Flow_{Bike})$	1.567

When the model is run there is a relation between the bicycle crashes and complexity if the p value is lower than 0,05. This means that the model falls within the 95% confidence interval. Then with the help of the B value the relation can be given. This relation can be calculated in the following ways.

- If the variable is a dichotomous predictor variable the increase of bicycle crashes in comparison with the reference category is: $100(e^B - 1)\%$
- If the variable is a continuous predictor variable the increase of bicycle crashes by an increase of 1 unit of complexity is: $100(e^B - 1)\%$

3.4. Binomial logistic distribution model

A binomial logistic regression predicts the probability that an observation falls into one of two categories of a dichotomous dependent variable based on one or more independent variables that can be either continuous or categorical (Laerd Statistics, n.d.). In this research this model is used to determine whether bicycle crashes can occur at intersection or not and if severe bicycle crashes can occur at intersections or not. This is determined with the help of the Conflict points and PIARC method as well as the traffic flow for cars and bicycles. First the data of the bicycle crashes needs to be dichotomous. This is done by looking if an intersection had at least one bicycle crash. If the intersection had at least one bicycle crash a score of 1 was given, if the intersections had no bicycle crashes a score of 0 was given. The same applies for the severity. This was done with two types of severity. Type 1 is if the victim was at least light wounded and type 2 is if the victim is at least hospitalized.

3.5. Example of the methods

3.5.1. Conflict points method

With the help of CycloMedia a satellite image is taken. This image is printed on an A3 paper. Then all the driving lines of the different vehicles are drawn. A driving line is the line a vehicle takes if it drives according to the rules of the intersection. There are a couple exemptions on this, firstly a car that makes a U-turn. This is often not prohibited, but it also rarely occurs that is decided to take these not into account. The second exemption is the pedestrian. In the Netherlands there are no rules where a pedestrian is allowed or is not allowed to cross the road. This would mean that there is an infinite amount of possibilities for pedestrians to cross the road. Therefor only the clear locations where pedestrians are assumed to cross the roads are considered. These locations are for example zebra’s, lined areas for pedestrians or locations where the sidewalk is slanted to make it easier for pedestrians to cross the road.

After drawing the driving lines the conflict points can be counted. A conflict point is the location where two driving lines intersect each other. It is possible that three or more lines seem to intersect at the same location. This is not counted as one conflict point. For every two lines that intersect a conflict point is counted. Therefor a location with three lines intersecting each other at the same location has three conflict points instead of only one see Figure 4 (Black & Red, Blue & Black, Blue & Red). At a location where two driving lines merge and continue as one driving line it is also counted as one conflict point see Figure 4 (Green & Bleu). The conflict point is at the location where the two lines merge. When two driving lines divide see Figure 4 (Green & Red) it is not counted as an conflict point because they were already on the same driving line before the dividing point. All the different types of conflict points are counted.

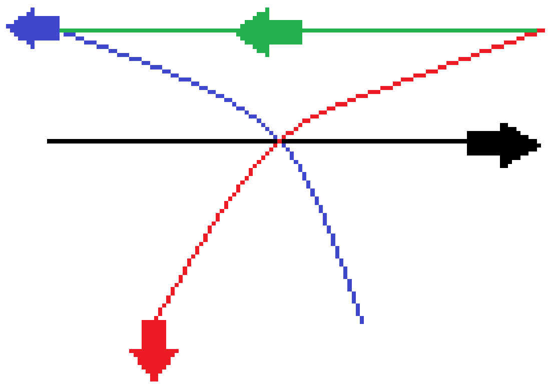

Figure 4: Example of driving lines

Next to these conflict points a special type of conflict points are determined also. These are the so called conflict points without speed reduction. A line is assumed to drive without speed reduction when the line is going straight and there for not forced to reduce the speed. The conflict point without speed reduction is at a location where two lines intersect, at least one of the lines is assumed to drive without a speed reduction, and this line must be a motorized vehicle (Car or Public

Transport). When bicyclists and pedestrians intersect, this is also counted as a conflict point without speed reduction if the bicyclist is going straight. Just like the normal conflict points all the different types of conflict points without speed reduction are counted. In Appendix B: Example of the conflict points method an example is given how the conflict points method is assessed.

3.5.2. PIARC method

The PIARC method is determined using CycloMedia images. The first 6 characteristics (Time to respond) are determined using images at 100 to 50 meter in front of the intersection. The other characteristics are determined using images just in front of the intersection. Every direction of every intersection is assessed. For every characteristic the average score is calculated per intersection. The reason for these average scores is because some intersections are three and some are four-way intersections. Without these average scores, a three-way intersection would always be worse than a four-way intersection.

Scores were given for each of the characteristics, what scores are given for a characteristic can be found in Table 14 of Appendix C: Example of the PIARC method, as well as an example intersection and which scores are given for this intersection.

3.5.3. Negative binomial regression model

The results of the negative binomial regression modal are acquired with the help of SPSS. With the help of the negative binomial regression model the following equation: $Y = a + bX + Offset$ can be completed. In this example the relation between the bicycle crashes and the PIARC score are determined. The used data are the amount of bicycle crashes (Y), the PIARC score (X), bicycle traffic flow (Offset) and the car traffic flow (Offset). The SPSS code looks like the following:

```
* Generalized Linear Models: Negative binomial regression for PIARC.
GENLIN Crashes WITH PIARC
  /MODEL PIARC INTERCEPT=YES OFFSET=LN_TOT2_INT
 DISTRIBUTION=NEGBIN LINK=LOG
  /CRITERIA METHOD=FISHER(1) SCALE=1 COVB=ROBUST MAXITERATIONS=100
MAXSTEPHALVING=20
    PCONVERGE=1E-006(ABSOLUTE) SINGULAR=1E-012 ANALYSISTYPE=3(LR) CILEVEL=95
CITYPE=WALD LIKELIHOOD=FULL
  /MISSING CLASSMISSING=EXCLUDE
  /PRINT CPS DESCRIPTIVES MODELINFO FIT SUMMARY SOLUTION.
```

After running this code, the results that can be found in Appendix D: Example of the negative binomial regression model showed up. The previous equation can then be completed and looks like the following: $Crashes = -17.175 + 0.235 * PIARC + \ln(Flow_{Car} * Flow_{Bike})$. Since PIARC is a continuous predictor the following rule should be followed to determine the effect of PIARC:

- If the variable is a continuous predictor variable the increase of bicycle crashes by an increase of 1 unit of complexity is: $100\left(e^{b} - 1\right)\%$

After filling in the 0.235 at the b the equation results in $100(e^{0.235} - 1)\% = 26.49\%$. This means that every time the PIARC score becomes 1 unit higher the amount of bicycle crashes increases by 26.49%.

3.5.4. Binomial logistic distribution model

Like the negative binomial regression model the results for the binomial logistic distribution model are acquired with the help of SPSS. It predicts a relation between the variables and then validates this. The validation is done by following the rules of the relation and determine for each intersection if a bicycle crash occurs or not. The best relation is than given and how significant each variable is. As an example the possibility of a bicycle crash occurring at an intersection in relation with the conflict points method is given. The script in SPSS looks like this:

```
LOGISTIC REGRESSION VARIABLES Crash
  /METHOD=ENTER Conflictpunten LN_MVT_INT LN_FTS_INT
  /CRITERIA=PIN(.05) POUT(.10) ITERATE(20) CUT(.5).
```

The results that appeared after running this code can be found in Appendix E: Example of the binomial logistic distribution model. The results can be interpreted in the as follows: The logistic regression model was statistically significant, $\chi 2(3) = 20.390$, $p < 0.001$. The model explained 44.7% (Nagelkerke R2) of the variance in bicycle crashes and correctly classified 66.0% of cases. The only significant variable is the LN_FTS_INT, which is the bicycle flow. An increase in bicycle flow increases the possibility of a bicycle crash occurring at the intersection.

4. Data

For this research some data is needed. To be precise there are three sets of existing data used. Firstly, a dataset of the bicycle crashes at intersections. A second dataset consists of data of characteristics of intersections. The last dataset is used to determine the bicycle traffic flows at the intersections. The datasets of the intersections and bicycle crashes are linked to each other with the so called KPID. This is the number of a specific intersection. The traffic flow of the bicycles is linked to the intersections with the help of the street names.

4.1. Bicycle crash data

The bicycle crash data consists of intersections with some characteristics. These characteristics are later used to select the intersections for the research. The first characteristic is the KPID, which is used to link it with the other dataset. The second characteristic is the street names and coordinates of the intersection. With the help of GIS the exact location of the intersection can be found and it makes it possible to link it with the bicycle traffic flow. The next characteristic is the type of intersection. Other characteristics are the attendance or absence of traffic signals, the mean 24 hours traffic flow of cars and the number of crashes that involved bicyclists. The bicycle crashes that are counted in this data are based on BRON data over the period of (2008-2015). BRON Data is: File Registered crashes in the Netherlands. The BRON system is kept up to date by DVS based on the crash registration forms provided by the police. BRON should contain all traffic crashes on Dutch roads, but it has been found that this is not the case. In principle, the rule applies: the more serious the crash, the better registered (about 94% of crashes with fatalities and only 10% of crashes with minor injuries) (SWOV, 2010). These crashes are divided in 5 categories: dead, hospitalized, first aid, light wounded and UMS. Added to this data is a summation of the total crashes with bicyclists involved. A crash is classified in a category based on the victim that comes of worst of the crash. For example: a car driver must break very hard for a cyclist. The car and cyclist have a minor collision, but due to the fierce braking a child in the back of the car who was not wearing a seatbelt is catapult towards the windscreen. The child is injured and must go to the hospital. This crash would be counted as a hospitalized crash , although the cyclist is completely fine. This crash is counted towards the total amount of bicycle crashes. This does have influence for the severity of the crash, but this is used to a lesser extent in this research. Also, there will not be many cases, where the injury of people in the car is more serious than the injury of the cyclist.

4.2. Intersections data

The intersections data consist of the same intersections as the bicycle crash data. In this dataset some of the specific properties of intersections are given. The intersections in this data set have the same KPID as the intersection of the bicycle crash dataset. The properties that are known and could be used for the PIARC method are: attendance of traffic signals, signage, priority arrangement, distinction hardening, direction choice, driving direction separation, horizontal alignment, zebra, bicycle facilities and bus/tram facilities. It is possible that for some intersection the properties are, partially, unknown. CycloMedia imagery is then be used to supplement the data.

4.3. Bicycle traffic flow data

This data set consists of streets where the bicycle traffic flows are known. The bicycle traffic flow is based on an average of the results of the Fietstelweek 2015 and 2016. The traffic flow is based on the cyclist in Amsterdam, this were 2508 cyclist in 2015 and 2244 cyclist in 2016 (SWOV, 2017). Even though the data is based on a portion of the cyclist in Amsterdam it gives a reliable relative value. When for example the given traffic flow at a certain street is twice as high as at another street you can assume that the actual traffic flow is also approximately twice as high at the first street in comparison with the second street. These traffic flows will be used to determine the traffic flow at the intersections used in the research.

4.4. Privacy

The data of the crashes are confidential. They consist for a part of ambulance crashes. In general, the crashes are anonymized, but in some cases the number of crashes is close to zero. Therefore, only the KPID will be used in the report and the names of the intersections will not be used.

5. Chosen intersections

To start the research the intersections that will be examined have to be chosen. Firstly, the region where the intersections are located will be chosen. To make sure that the methods used in this research can be examined the region of the intersections has to comply with the following requirements:

- Bicycle crash data available for several years
- Traffic model data available
- Located in the same region
- Homogeneous type of intersections

There are two regions where the SWOV has a large amount of data available that is sufficient for this research. These are the Ambulance data from the province of Flevoland and the BRON data (Police registered data) from the city of Amsterdam. To choose the region from which intersections will be used the statistics per region are put in Table 4.

Table 4: Statistics for Flevoland and Amsterdam

Flevoland	Amsterdam
More bicycle crash data (ambulance)	Less bicycle crash data (BRON)
Unknown traffic flows	Generally known traffic flows
No database intersection characteristics	Database intersection characteristics
Big area	Small area
Cities and rural areas	City
No database	Wide database makes it possible to choose a mixture of intersections both in the inner city as well as the suburbs.

Based on this table the decision is taken to use intersections located in the city of Amsterdam, mainly because the most data about the intersections are known. This means that most of the data are already available and there is less time wasted trying to gather missing data. Another benefit is that, if it is needed, the intersections are easy to visit due to the relatively small area of Amsterdam in comparison with Flevoland.

5.1. Choosing specific intersections

After the decision of the region the specific intersections can be chosen. The data of Amsterdam consists of 1587 intersections. Not all the intersections can be used for this research. To reduce the number of intersections the following steps are taken. Firstly, only the intersections that consist of area access roads, with a speed limit of 50 km/h, will be used. These are 801 intersections. After deleting the roundabouts and the intersections with a traffic flow of 0, there are still 577 intersections left. These are divided into two groups: Intersections with traffic signals (226) and intersections without traffic signals (351). From these groups random samples will be taken to get a variety of intersections. These random samples are selected using a randomizer (RANDOM.ORG, 2019). Here the list with all the intersections are placed. After clicking the randomize button the intersections are given in a random order. The highest intersections are chosen to use in the research. The intersections will then be checked along the following requirements:

- Pictures and or satellite images available
- No interim changes to the intersection (During the period of the available data)
- No interim changes in the nearby road structure

If the intersections satisfy these requirements the intersection can be examined with both methods. The assumption is that this will give a clear view of what type of complexity influence safety and which do not influence safety. To get reliable results from the negative binomial regression model a significant sample size should be chosen. The rule of thumb that is used in this research is to take for every variable 10 to 15 intersections (Babyak, 2004). Because at max 5 variables (Presences or absence of VRI, amount of conflict points, PIARC score, car traffic flow, bicycle traffic flow) will be used at the same time and the given the limited timeframe, 50 intersections are used. The decision is made to assess 25 intersections with traffic signals and 25 intersections without traffic signals. The selected intersection can be found in Appendix A: Chosen Intersections. Figure 5 shows the distribution of the total group of intersections (Orange) and the distribution of sample of the intersections used in this research (Blue). It shows that the distribution of the sample is similar to the total amount of intersections and therefore is a representative sample of the total group.

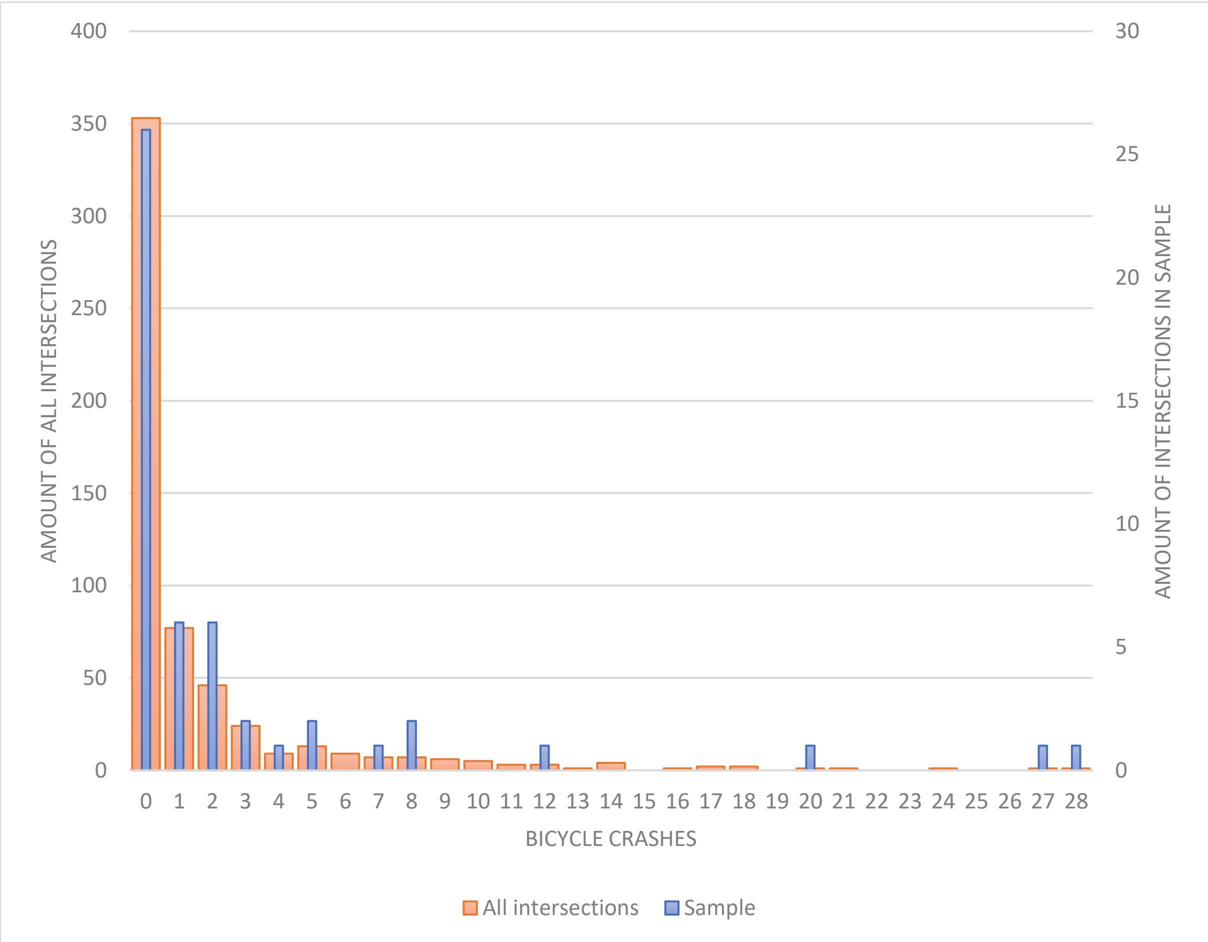

Figure 5: Distribution of amount of bicycle crashes at the intersections

5.1.1. CycloMedia

Whether the intersections meet the requirements stated in the subchapter 'Choosing specific intersections' is decided with the help of CycloMedia. CycloMedia is an application specialized and leading in the systematic and on large scale mapping public spaces. This is done with 360° street photos and aerial photos with GIS-accuracy. Thanks to unique camera and processing techniques are large areas mapped on daily basis. These maps are collected in databases, which makes it possible to go back in time to check whether the infrastructure, and its surrounding, has changed (CycloMedia, n.d.).

6. Results

6.1. Results of methods

After assessing all the intersections the following results have been found. In Figure 6 the amount of bicycle crashes is plotted against the car traffic flow. In Figure 7 the amount of bicycle crashes is plotted against the bicycle traffic flow. These traffic flows will be used as an offset variable to determine the relation between the amount of bicycle crashes and complexity at an intersection. In first insight there is no immediate clear relation between the traffic flow and the amount of bicycle crashes, which indicates that there is another factor that influences the amount of crashes at an intersection.

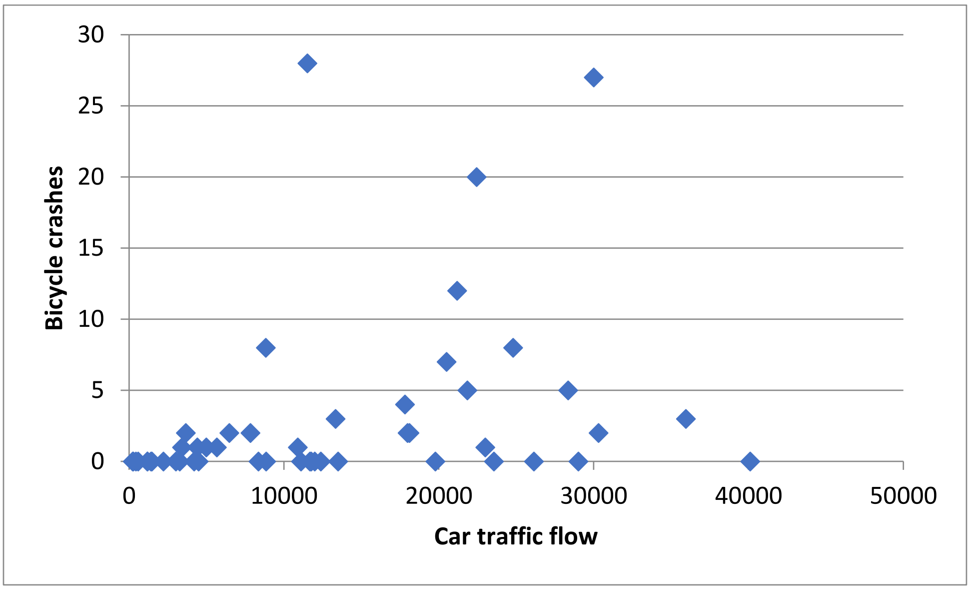

Figure 6: Bicycle crashes and car traffic flow

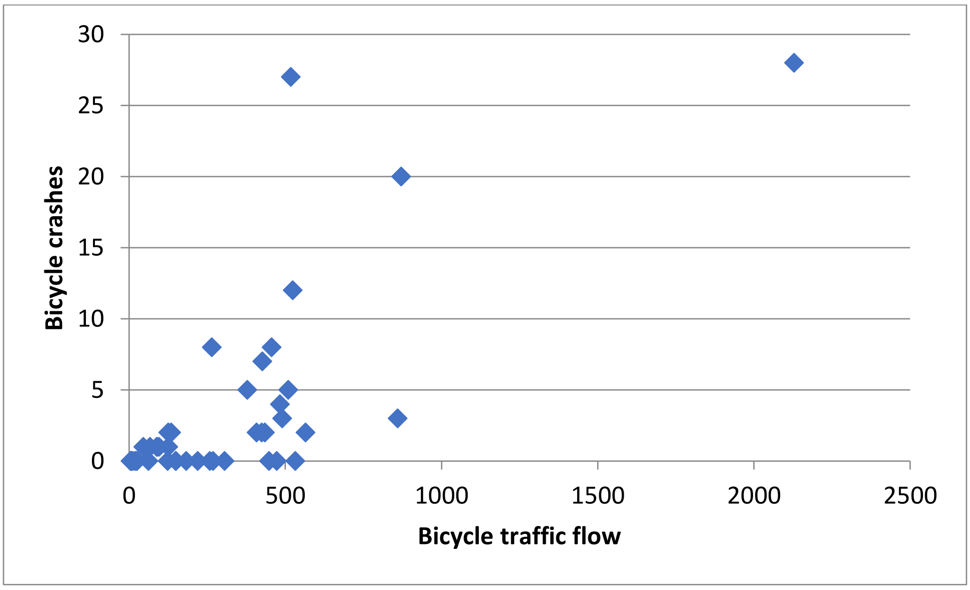

Figure 7: Bicycle crashes and bicycle traffic flow

Figure 8 shows the bicycle crashes plotted against the number of conflict points. Notable is that the three intersection with the highest number of conflict points are not the same as the three intersections with the highest number of bicycle crashes. The intersection with the highest number of conflict point does not even have a bicycle crash. In Appendix F: Results conflict points all the results of the conflict point method can be found.

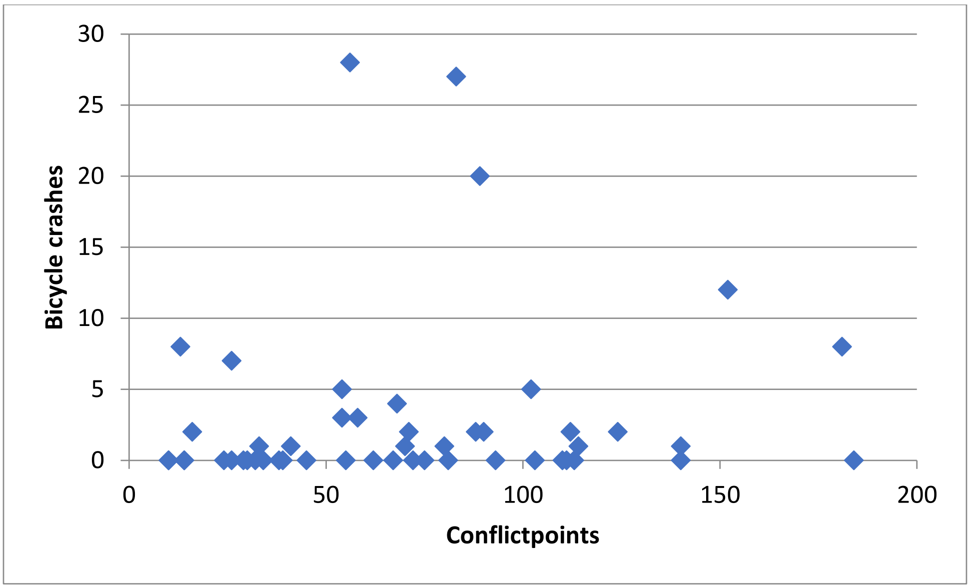

Figure 8: Bicycle crashes and conflict points

Figure 9 shows the bicycle crashes plotted against the PIARC scores. It seems that the lower the PIARC score the higher the amount of bicycle crashes is. Although there is one intersection with a high PIARC score but also a significant amount of bicycle crashes. In Appendix G: Results PIARC all the results of the conflict point method can be found.

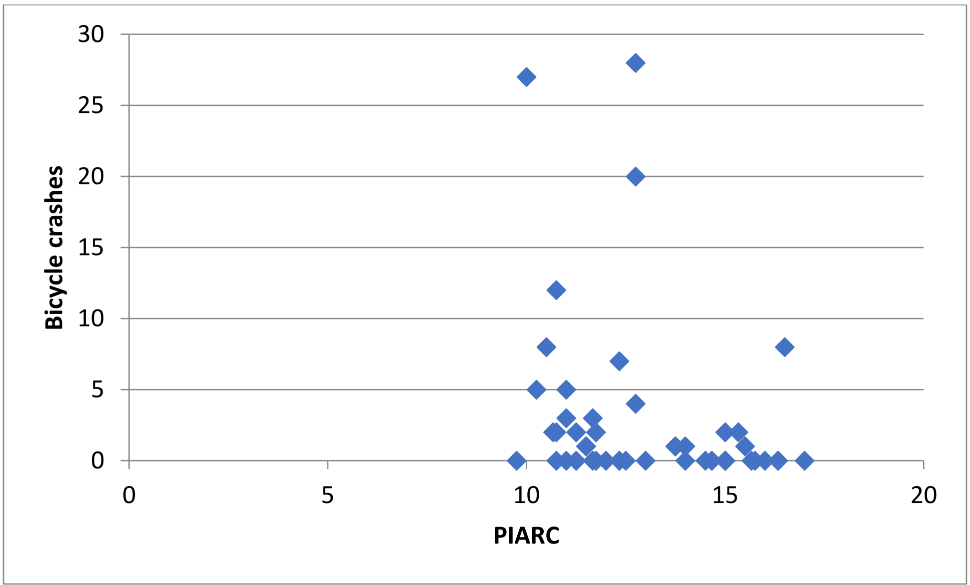

Figure 9: Bicycle crashes and PIARC scores

The next step is to use these results with the negative binomial regression model to determine if there are relations between the intersections and the complexity at an intersection. All the other results that are acquired for this research can be found in Appendix H: Other results

6.2. Results main question

What is the relation between complexities at an intersection and the number of bicycle crashes?

The main question is answered with the help of the three sub questions of which the results are given in the next parts. There are three things that can be said about these results

Firstly, there is no clear relation found between bicycle crashes and conflict points. The relations that were given with the help of the negative binomial regression model were not significant, within a 95% confidence interval, and thus the only conclusion on this part of the research is that there is no relation found.

The PIARC method did show significant relations between the complexity on the road section leading to the intersection and bicycle crashes. When an intersection has a low PIARC score, less complex, there were more bicycle crashes than when the PIARC score was high, more complex. This relation is that when an extra characteristic is present, the amount of bicycle crashes decreases with 26,5%. For the most individual characteristics a similar trend was found.

The Last sub question shows that when an intersection is a 4-way intersection there occur more bicycle crashes than at a 3-way intersection. And with the help of the binomial logistic regression there were no relations found between the probability a (severe) bicycle crash could happen at an intersection and the complexity methods.

6.3. Results sub question 1

What is the influence of conflict points on the number of bicycle crashes?

The results of the negative binomial regression models executed with several types of conflict points in SPSS can be found in Table 5. The traffic flows of both the cars and bicyclists are in every case taken into account as offset variables. Two things stand out in this table. Firstly, the Goodness of Fit is in all the situations below 1, which is good and therefor the model is reliable. The second striking results of the models is that the p value is in all the cases greater than 0,05. To have a significant result the value p should be smaller than 0,05 and therefor there is no relation found in any of the conflict points types.

Table 5: Results of Conflict points

Type of conflict points	Goodness of Fit	p	B	% increase bicycle crashes
Total Conflict Points	0.955	0.368	-0.004	-0.40%
Total Bicycle Conflict Points	0.969	0.799	-0.003	-0.30%
Bicycle vs Car Conflict points	0.971	0.993	0.000	0.02%
Total Conflict Points, without speed reduction	0.955	0.384	-0.006	-0.60%
Total Bicycle Conflict Points, without speed reduction	0.97	0.843	-0.004	-0.40%
Bicycle vs Car Conflict Points, without speed reduction	0.971	0.897	0.009	0.90%

6.4. Results sub question 2

What is the influence of intersection characteristics on the number of bicycle crashes?

First thing that stands out is that all values have a good goodness of fit. The results of this sub question are described in two parts. Firstly, the overall results of the PIARC method are given and then the results of the individual characteristics. Higher PIARC values, means that an intersection is less complex.

As can been seen in Table 6 are the PIARC and Steering of Maneuvers significant. The traffic flows of both the cars and bicyclists are in every case taken into account as offset variables. For both the PIARC and the Steering of Maneuvers the amount of bicycle crashes increases when their value gets higher; less complex intersections have higher amounts of bicycle crashes. Time to respond and adjust speed are not significant, but their value is not extremely far of and you could assume that they indicated that, just like the two other characteristics, when the value increases, the amount of bicycle crashes also increases. This complies with the previous study (SWOV, 2015).

Table 6: Results of PIARC scores

PIARC main parts	Goodness of Fit	p	B	% increase bicycle crashes
Overall PIARC score	0.864	0.021	0.235	26.49%
Time to Respond	0.926	0.19	0.317	37.30%
Adjust Speed	0.929	0.164	0.963	161.95%
Steering of Maneuvers	0.826	0.001	0.53	69.89%

Table 7 shows the results of the individual characteristics and their influence on bicycle crashes. The traffic flows of both the cars and bicyclists are in every case taken into account as offset variables. For the continuous variables the last column means that if the score is 1 unit higher (E.g. lighting on both sides instead of only on one side.) the number of bicycle crashes increase by the percentage given. For the Dichotomous variables the last column means the number of bicycle crashes increase by the percentage given if the characteristic would be absent instead of present.

Looking at the continuous variables, the following can be said. Lighting has a good p value, and it shows that the higher the value, the less bicycle crashes. The higher the value, the more lighting is available, thus this is an expected result. Visibility triangle has a very high p value and thus does not say anything about the amount of bicycle crashes. It is even that far of that you cannot say it indicates that the better field of view gives more bicycle crashes. Nearly all the intersections in the sample of intersections had the same value for the field of view. Therefor it was not possible to run a model in SPSS with this characteristic without getting warnings and error messages.

Results of the dichotomous variables can be described as follows. All but three characteristics have a good p value. These three characteristics are: Signage, Horizontal alignment and Bus/Tram facilities. Their p values are far from the required p value, so there is no evidence for their relation with bicycle crashes. The significant characteristics show that for most it accounts that if the characteristic is present it reduces the amount of bicycle crashes. Only the speed control and distinction hardening increase the amount of bicycle crashes when they are present. This could be caused by the fact that these only appear at intersections, in this dataset, that have a low complexity score and are therefore warn drivers not enough there is an intersection. Another possible reason is that these characteristics are not specific for an intersection, you can find surfaces changes or speedbumps also on a straight road without an intersection. The remainder of characteristics that are significant show that the amount of bicycle crashes increases by over 180% if they are absent instead of present. The absence of bicycle facilities increases the amount of bicycle crashes even by 443%. The reduction of bicycle crashes by the presence of characteristics complies with the previous study which concluded that bicycle facilities reduced the possibility of bicycle crashes by 42%, street markings reduced the possibility by 58% and traffic signs reduced the possibility by 80% (Hamann & Peek-Asa, 2013).

Table 7: Results of PIARC individual characteristics

Characteristics of intersection	Continuous or Dichotomous	Goodness of Fit	p	B	% increase bicycle crashes (if characteristic is absent)
Lighting	Continuous	0.911	0.013	-1.77	-82.97%
Visibility triangle	Continuous	0.970	0.823	0.104	10.96%
Field of View	Continuous	-	-	-	-
Traffic Signals	Dichotomous	0.794	<0.001	1.280	259.66%
Speed Control	Dichotomous	0.930	0.003	-0.881	-58.56%
Signage	Dichotomous	0.971	0.968	0.025	2.53%
Priority arrangement	Dichotomous	0.900	0.027	1.030	180.11%
Distinction hardening	Dichotomous	0.934	0.001	-1.013	-63.69%
Direction choice	Dichotomous	0.817	0.002	1.169	221.88%
Driving direction separation	Dichotomous	0.856	0.003	1.294	264.73%
Horizontal alignment	Dichotomous	0.971	0.876	0.067	6.93%
Zebra	Dichotomous	0.836	0.001	1.210	235.35%
Bicycle facilities	Dichotomous	0.922	<0.001	1.693	443.58%
Bus/Tram facilities	Dichotomous	0.962	0.524	0.300	34.99%

6.5. Results sub question 3

Are there other design factors that could influence (severe) bicycle crashes?

6.5.1. Other Design factors

The only noticeable design factor that was noticed during the assessment of the intersection was whether the intersection was a three way or a four-way intersection. Other design factors where already assessed for the PIARC scores. With a binomial logistic regression model the probability whether bicycle crashes could occur at an intersection is researched, as what the probability is on severe bicycle crashes on two levels.

The results of the influence of number of ways of an intersection can be found in Table 8. The Goodness of fit is 0,885 and thus close to 1 and it has a p value <0.05 and thus falls within the 95% confidence interval. The reference category was in this situation the 4-way intersections. Therefore, it can be concluded that a 3-way intersection has a lower amount of bicycle crashes. The increase is -62% in comparison with a 4-way intersection. This is contradictory to the conflict points method which showed no relation.

Table 8: Results 3- or 4-way intersection

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	p
3 way (instead of 4 way)	-0.972	0.425	-1.805	-0.139	5.233	1	0.022
Intercept	-14.013	0.243	-14.490	-13.537	3323.555	1	<0.001

6.5.2. Binomial logistic regression models

The following tables show the results of the binomial logistic regression models. The % accuracy shows how accurate the prediction of the model was. They all have an accuracy of around 75%. The P value is should be <0.05 to be significant. The EXP(B) value is the influence on the probability if a (severe) bicycle crash can occur at the intersection. The probability of a bicycle crash multiplies by EXP(B) if the corresponding input data increases by 1. The striking results are that there are no significant influence of any of the complexity methods, for the probability that bicycle crashes can occur (Table 9) and how severe bicycle crashes can occur (Table 10 and Table 11) at an intersection. In all cases, even when the both methods are combined, the only significant indicator is the bicycle flow. This would assume that only the bicycle flow influences the probability whether a (severe) bicycle crash can occur at an intersection. A complete overview with all the results can be found in Appendix J: Results binomial logistic distribution models.

Table 9: Binomial model with crash or not

Method	% accuracy	Conflict points		PIARC		Car flow		Bicycle flow	
		P	Exp(B)	P	Exp(B)	P	Exp(B)	P	Exp(B)
Conflict points	66	0.807	1.002			0.763	0.863	0.009	2.858
PIARC	70			0.716	1.098	0.990	1.006	0.009	2.879
Combined	68	0.562	1.005	0.606	1.194	0.982	0.988	0.008	3.023

Table 10: Binomial model with Injured or not

Method	% accuracy	Conflict points		PIARC		Car flow		Bicycle flow	
		P	Exp(B)	P	Exp(B)	P	Exp(B)	P	Exp(B)
Conflict points	74	0.970	1.000			0.662	0.774	0.007	4.440
PIARC	78			0.502	1.218	0.984	0.987	0.007	4.755
Combined	74	0.699	1.004	0.442	1.306	0.989	0.991	0.007	5.020

Table 11: Binomial model with hospitalized or not

Method	% accuracy	Conflict points		PIARC		Car flow		Bicycle flow	
		P	Exp(B)	P	Exp(B)	P	Exp(B)	P	Exp(B)
Conflict points	76	0.869	0.999			0.804	1.157	0.020	3.078
PIARC	78			0.529	1.193	0.600	1.436	0.017	3.275
Combined	78	0.825	1.002	0.518	1.242	0.597	1.442	0.020	3.377

7. Discussion

Looking at the results there was no relation found between the conflict points and the amount of bicycle crashes. This was a little bit unexpected because a previous study (SWOV, 2015) had shown that there was a relation between the conflict points and amount of crashes. Back then it was performed on a smaller scale then this research. This small scale could have led to a coincidental relation. Another possible reason why this research shows different results than the previous study is because this research used intersection within a city whereas the previous study used intersections on provincial roads.

The PIARC shows that if an intersection has more characteristics, less bicycle crashes occur. This sounds contradictory, but a characteristic makes people aware of an intersection and most characteristics also guide the driver over the intersection. This guiding makes it easier and safer to cross the intersection and thus if everyone follows the guiding there should be no bicycle crashes. Also, the PIARC relation with the amount of bicycle crashes is substantiated by most of the individual characteristics.

The results of the 3- and 4-way intersection show that a 4-way intersection has more bicycle crashes than a 3-way intersection. This is contradictory to the results of the conflict points method which showed no relation. In general, a 4-way intersection has more conflict points than a 3-way intersection. This could mean that the conflict points method is too complicated to determine a relation, where a simplified method can show a relation.

The binomial logistic regressions did not show any relation for the probability of a (severe) bicycle crash to happen in relation with the complexity methods. Probably because a bicycle crash can happen at any moment. For the negative binomial regression models one bicycle crash that has nothing to do with the intersection has barely any influence where this does have a big influence on the binomial logistic regression model. For the binomial logistic regression models only the fact if a crash has happened is taken into account and not how many.

There are also a couple of notable points that could influence the results, but where not taken into account for this research. These are mainly the behavior of people and the conditions around the intersection. For the conflict point method it is assumed that everyone follows the rules. In reality drivers and cyclist ignore red lights, use their smartphone while driving, drive under influence of alcohol or drugs, drive whilst being tired or are distracted by other things. All these rule breaks could cause bicycle crashes which have nothing to do with the design of the intersection, but still influence the results of the relations.

Next to the behavior of people the surrounding could influence results. For example, the quality of the roads or because Amsterdam is a big city with a lot of tourist who are possibly not aware of the traffic situation in the Netherlands especially when it comes to cycling. Other factors are the time of year or the time of day. The visibility is influenced by the (absence of the) sun. As well as trees are in the summer way more of a view blocker than in the winter. And the weather conditions differ from time to time, in the rain or snow it is most likely more dangerous than on a dry day. And closed streets in the neighborhood can influence the traffic flow.

Most of these factors do have influence, but due to the timeframe of 8 years and since the intersections are in the same city those factors are similar for each intersection. That is also why the intersections use should be from the same area.

Possible limitations in this research are mainly on the data part of the research. Due to the time frame the minimum amount of intersection for the research was taken. Also, the bicycle crash data is limited. Especially during the period of 2009-2014 there was under registration of crash data. The BRON data of the police registration. Only the major crashes with bicyclist involved were registered and most of the smaller crashes not. Therefore, the amount of registered bicycle crashes is low and the influence of single bicycle crashes that did not had anything to do with the intersection have more influence on the results of this research.

8. Recommendation

Based on the results of this research, which show that there are less bicycle crashes when there are more characteristics at an intersection, it can be recommended to add as much characteristics as possible at an intersection. This will make sure that drivers are aware that they are entering an intersection and drive more carefully. The guidance of the different types of traffic with the help of the characteristics will improve the safety of an intersection. Since it is not possible to have every intersection with all the characteristics it is advised to start with the bicycle facilities since these reduce the amount of bicycle crashes the most.

For future research it is recommended to have more bicycle crash data. Bicycle crashes are under registered. This means that there are in general not much known and well documented bicycle crashes per intersection. Therefor a bicycle crash that had nothing to do with the complexity has a relative strong influence on the results. If there are more bicycle crashes this incidental bicycle crash does not have that much influence. More bicycle crash data can be acquired by using a larger timescale. Other possibility is to use ambulance crash data instead of BRON data. The ambulance data is more accurate when it comes to the amount of bicycle crashes. This can be used for the factors that were insignificant in this research. The more accurate data can be used to determine if there is a relation between the insignificant factors and the amount of bicycle crashes or to confirm what was found in this research.

Other research can focus on the conflict points method, why did it show a relation in the previous study and why not in this study. As well as why did the difference in a 4- or 3-way intersection do show a relation with the bicycle crashes and the conflict point method did not show this relation.

And lastly the PIARC method could be more dived into, for example why did some characteristics, like speed control and distinction hardening, show the opposite of what the other characteristics showed and the total PIARC as well. Or the relation between different types of characteristics can be investigated. For example, what the influence of one type of characteristic has on another and what the relation is between these characteristics combined and the bicycle crashes?

9. Conclusion

Based on the results, there is no relation between the conflict points and the bicycle crashes. The assumption is that more conflict points lead to more bicycle crashes. The reason that there is no relation cannot be said with 100% certainty, but one of the possible explanations is that in the sample of intersections there were exceptions where there are lots of conflict points and no bicycle crashes or few conflict points and lots of bicycle crashes. Along with the intersections with few bicycle crashes and few conflict points and intersections with lots of bicycle crashes and lots of conflict points. This makes it nearly impossible to get a relation between the bicycle crashes and conflict points. Another possible explanation is caused by intersection with traffic signals. At those intersections there are often lots of conflict points, but due to the regulations with the traffic lights there are, unless people disobey the lights, only a few actual conflict points.

The relation of the bicycle crashes and PIARC method is that the more complex an intersection is the less bicycle crashes occur. At first this sounds contradictory, but there could also be some logical explanations for it. Most of the characteristics make people aware of the intersections. The more complex an intersection looks the more careful people will enter this intersection. Thus, the more complex means that people pay more attention. But, a couple of characteristics show it the other way around (Lighting, Speed control and Distinction hardening). The lighting, because when there is no or less lighting it makes it in the dark harder to see (Complex) and it does not show you that an intersection is coming. The speed control and distinction hardening are often at not so complex intersections and are not specific for an intersection. Therefor it does not warn people enough of the intersection and people pay less attention than when they see another characteristic.

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Appendix A: Chosen Intersections

Table 12 and Table 13 show the choses intersections, The KPID is the number of the intersection, The traffic lights column is to indicate from which sample the intersections are collected. Sample no. means the number of randomizations is used to collect this intersection. Meet requirements shows whether the intersection fulfilled the requirements. The car and bicycle traffic flow show the traffic flows that are used as offset variables. The bicycle crashes show the number of bicycle crashes at that intersection.

Table 12: Chosen intersections with traffic lights

KPID	Traffic Lights?	Sample no.	Meet requirements?	Car traffic flow	Bicycle traffic flow	Bicycle Crashes
365	Yes	1	No			
409	Yes	1	No			
720	Yes	1	No			
882	Yes	1	No			
1028	Yes	1	Yes	11679	258	0
1039	Yes	1	Yes	19778	123	0
1130	Yes	1	Yes	30308	408	2
1143	Yes	1	Yes	21179	523	12
1204	Yes	1	Yes	18101	424	2
1215	Yes	1	Yes	23561	305	0
1220	Yes	1	Yes	28998	268	0
1241	Yes	1	No			
1254	Yes	1	Yes	24787	456	8
1276	Yes	1	No			
1277	Yes	1	No			
1279	Yes	1	Yes	20489	426	7
1336	Yes	1	Yes	29990	517	27
1340	Yes	1	No			
1393	Yes	1	No			
1412	Yes	1	No			
1453	Yes	1	Yes	35943	489	3
1480	Yes	1	Yes	13315	859	3
1484	Yes	1	Yes	26136	531	0
1497	Yes	1	Yes	8849	447	0
1562	Yes	1	Yes	28346	378	5
790	Yes	2	Yes	10891	66	1
1054	Yes	2	No			
1060	Yes	2	No			
1070	Yes	2	Yes	22995	45	1
1223	Yes	2	Yes	6473	434	2
1268	Yes	2	Yes	12373	219	0
1370	Yes	2	Yes	3272	182	0
1389	Yes	2	Yes	21829	509	5
1405	Yes	2	Yes	40091	149	0
1514	Yes	2	Yes	17972	564	2
703	Yes	3	No			
1072	Yes	3	Yes	11974	19	0
1265	Yes	4	No			
1557	Yes	5	Yes	17812	482	4

Table 13: Chosen intersections without traffic lights

KPID	Traffic Lights?	Sample no.	Meet requirements?	Car traffic flow	Bicycle traffic flow	Bicycle Crashes
122	No	1	Yes	11756	8	0
141	No	1	Yes	3024	5	0
153	No	1	No			
191	No	1	No			
229	No	1	Yes	1455	5	0
253	No	1	Yes	3417	89	1
313	No	1	Yes	1180	5	0
332	No	1	Yes	1172	24	0
340	No	1	No			
490	No	1	No			
529	No	1	Yes	4400	125	1
542	No	1	Yes	3656	125	2
638	No	1	Yes	13495	61	0
644	No	1	Yes	7824	134	2
722	No	1	Yes	1401	6	0
736	No	1	Yes	2201	5	0
997	No	1	Yes	225	11	0
1004	No	1	Yes	8346	148	0
1012	No	1	Yes	4187	24	0
1053	No	1	No			
1179	No	1	Yes	22434	870	20
1194	No	1	No			
1199	No	1	Yes	260	18	0
1208	No	1	No			
1320	No	1	Yes	8817	264	8
121	No	2	No			
288	No	2	Yes	4480	5	0
551	No	2	No			
681	No	2	Yes	4982	95	1
1251	No	2	No			
1310	No	2	Yes	11501	2128	28
1413	No	2	Yes	11102	472	0
334	No	3	Yes	573	5	0
1172	No	3	Yes	5663	88	1
1494	No	3	No			
767	No	4	Yes	434	5	0

Appendix B: Example of the conflict points method

In Figure 10 the driving lines are drawn onto the intersection. Black are the driving lines of cars. Red are the riding lines of bicycles. Green are the walking line of pedestrians.

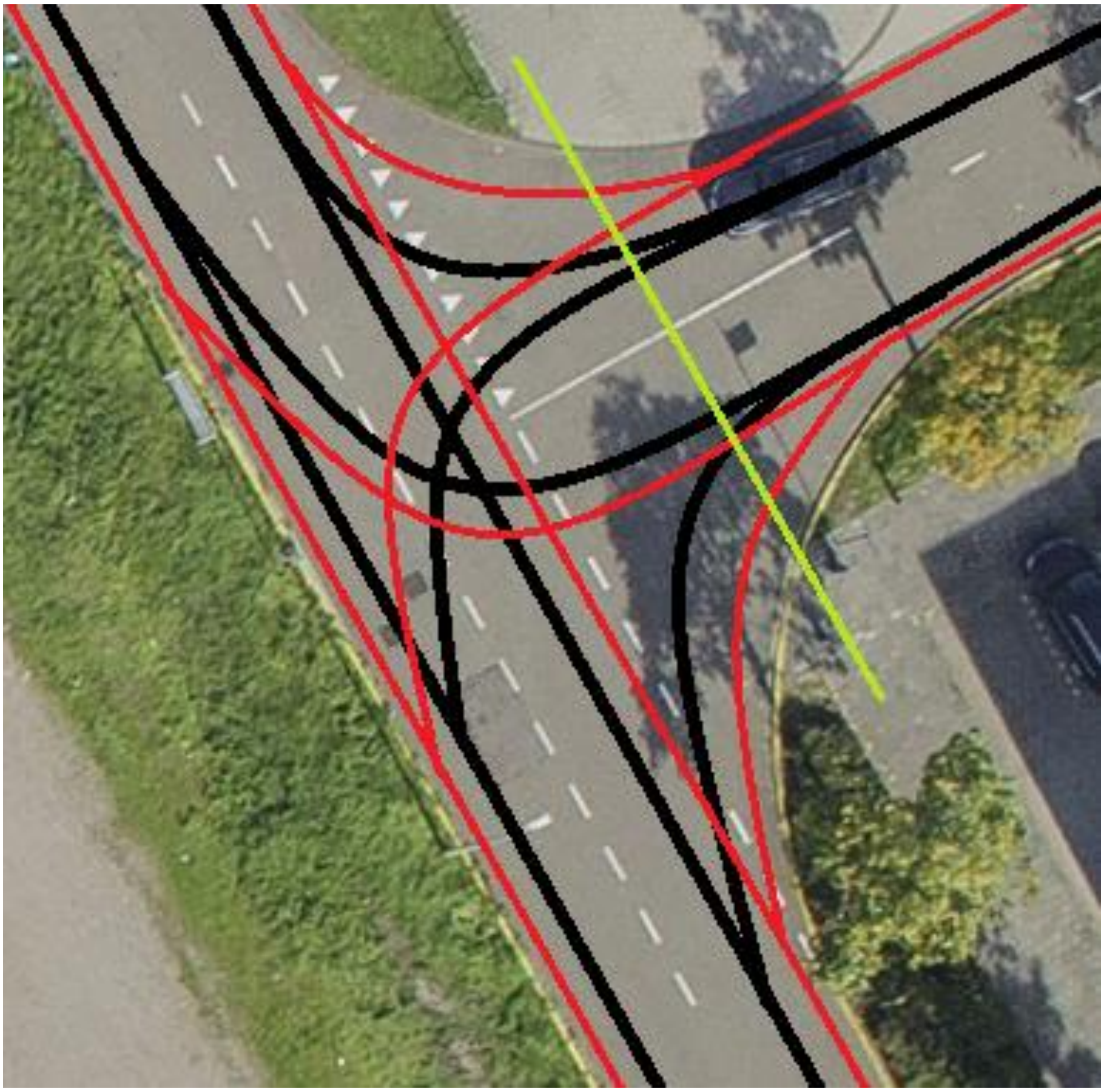

Figure 10: Example intersection with driving lines

In Figure 11 the conflict points are added. The squares represent the conflict points without speed reduction, the dots represent the other conflict points. Black are car versus car conflict points (6 total, 4 without speed reduction). Red are bike versus bike conflict points (6 total, 4 without speed reduction). Blue are car versus bike conflict points (12 total, 4 without speed reduction). White are car versus pedestrian conflict points (4 total, 0 without speed reduction). Orange are bike versus pedestrian conflict points (4 total, 0 without speed reduction).

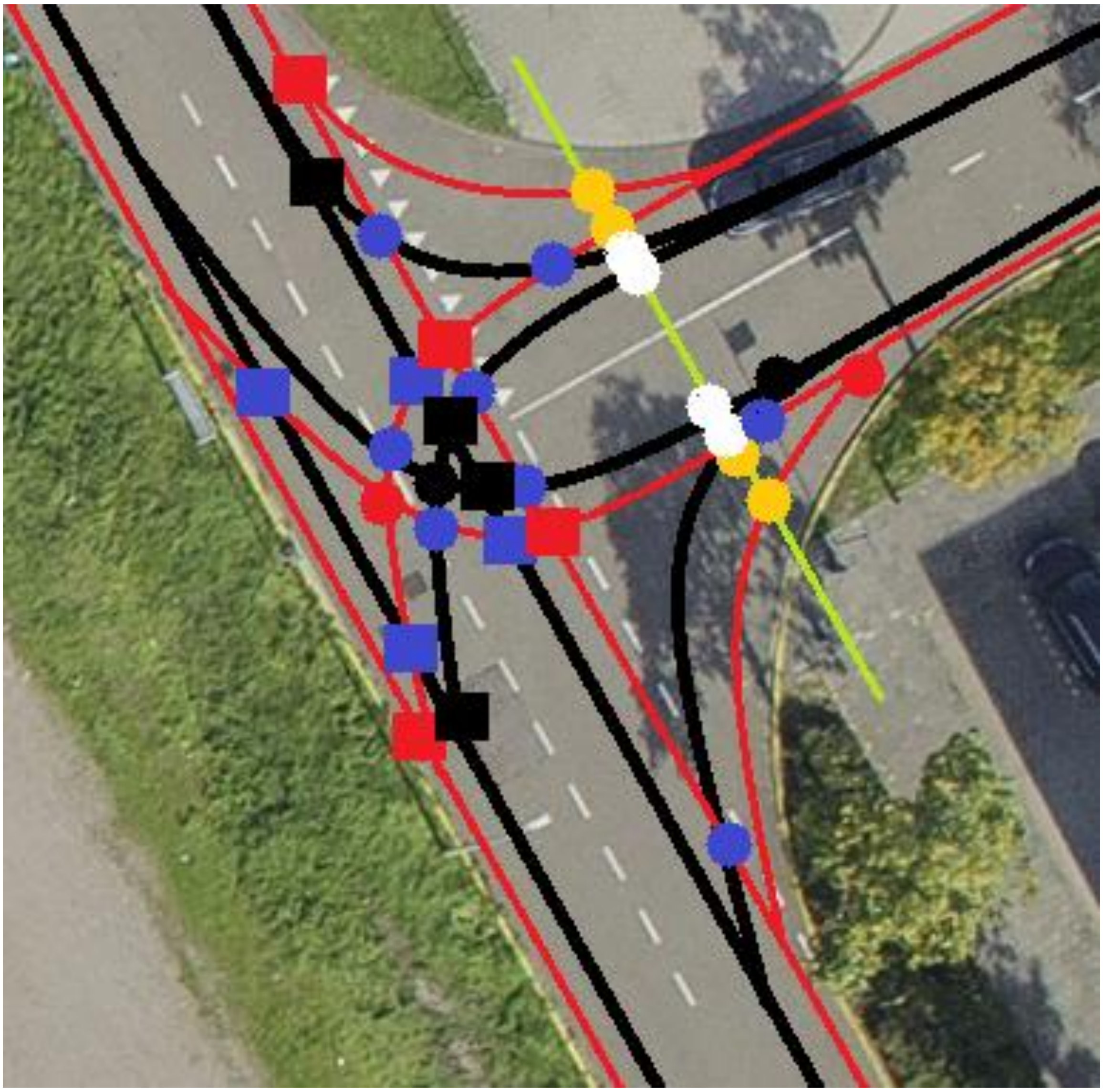

Figure 11: Example intersection with driving lines and conflict points

Appendix C: Example of the PIARC method

Table 14: How are the PIARC scores given per characteristic

Characteristic	Score based on	Score: 2	Score: 1	Score: 0
Lighting	Where is the Lighting?	Middle or Both sides	Left or right side	No Lighting
Traffic signals	Are there traffic signals?		No	Yes
Speed control	Is there an attempt to slow drivers down? (for example, speed bumps, narrowing road, ripples or lines on the road surface)		No	Yes
Signage	Are there road signs that show directions (like Figure 12)?  *Figure 12: Signage*		No	Yes
Priority arrangement	Is there a priority arrangement, given by signs or drawings on the road?		No	Yes
Visibility triangle	How well is the intersection and traffic on the other ways visible at 50-100m?	Good, intersection and other traffic is clear visible	Mediocre, the intersection is visible but only a limited part of the traffic on other ways is visible	Bad, unclear where the intersection exactly is or other traffic
Distinction hardening	Changes the type of surface?		No	Yes
Direction choice	Are there arrows on the road to show you where you can go?		No	Yes
Driving direction separation	Is there a physical barrier between the different driving directions?		No	Yes
Horizontal alignment	Are there lines to show where the lanes are?		No	Yes
Zebra	Is there a zebra crossing?		No	Yes
Bicycle facilities	Are there special facilities for bicyclist?		No	Yes
Field of view	How well is the view of the intersection when entering it?	Good, clear view of the entire intersection	Mediocre, view is not optimal or partly blocked by for example trees or bushes on the central reservation	Bad, view is blocked by obstacles
Bus/Tram facilities	Are there public transport facilities like bus stops, bus lanes or tram tracks?		No	Yes

In Figure 13 the images that were used to assess an intersection are displayed, during the assessment it was also possible to move closer or further away from the intersection as well as looking around to make sure that no details were overlooked. The results of the way direction east north east are displayed in Table 15. Keep in mind that these are the results of only one way of the intersection. The full results are acquired by averaging the scores of the other two ways.

Figure 13: Used images for PIARC method, direction ENE

Table 15: Results of the PIARC method of the ENE way displayed in Figure 13

Time to respond	Lighting	Right	1	5	14
	Traffic signals	No	1		
	Speed control	No	1		
	Signage	No	1		
	Priority arrangement	Yes	0		
	Visibility triangle	Mediocre	1		
Adjust speed	Distinction hardening	No	1	3	
	Lighting	Right	1		
	Direction choice	No	1		
Steering of maneuvers	Driving direction separation	No	1	6	
	Horizontal alignment	Yes	0		
	Zebra	No	1		
	Bicycle facilities	No	1		
	Field of view	Good	2		
	Bus/Tram facilities	No	1		

Appendix D: Example of the negative binomial regression model

SPSS results of a negative binomial regression model: PIARC in relation with the amount of bicycle crashes and the traffic flow as offset variable.

Generalized Linear Models

Model Information

Dependent Variable	ongevallen
Probability Distribution	Negative binomial (1)
Link Function	Log
Offset Variable	LN_TOT2_INT

Case Processing Summary

	N	Percent
Included	50	100,0%
Excluded	0	0,0%
Total	50	100,0%

Continuous Variable Information

		N	Minimum	Maximum	Mean	Std. Deviation
Dependent Variable	ongevallen	50	0	28	2,96	6,243
Covariate	PIARC	50	9,750000	17,00000	13,10500	2,051893
Offset	LN_TOT2_INT	50	7,68	17,01	13,5391	2,87469

Goodness of Fit[a]

	Value	df	Value/df
Deviance	41,459	48	,864
Scaled Deviance	41,459	48	
Pearson Chi-Square	31,806	48	,663
Scaled Pearson Chi-Square	31,806	48	
Log Likelihood[b]	-78,415		
Akaike's Information Criterion (AIC)	160,830		
Finite Sample Corrected AIC (AICC)	161,086		
Bayesian Information Criterion (BIC)	164,654		
Consistent AIC (CAIC)	166,654		

Dependent Variable: ongevallen
Model: (Intercept), PIARC, offset = LN_TOT2_INT[a]

a. Information criteria are in smaller-is-better form.

b. The full log likelihood function is displayed and used in computing information criteria.

Omnibus Test[a]

Likelihood Ratio Chi-Square	df	Sig.
5,164	1	,023

Dependent Variable: ongevallen
Model: (Intercept), PIARC, offset = LN_TOT2_INT[a]

a. Compares the fitted model against the intercept-only model.

Tests of Model Effects

Source	Type III Likelihood Ratio Chi-Square	df	Sig.
(Intercept)	1197,079	1	,000
PIARC	5,164	1	,023

Dependent Variable: ongevallen
Model: (Intercept), PIARC, offset = LN_TOT2_INT

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	-17,175	1,3272	-19,776	-14,573	167,448	1	,000
PIARC	,235	,1020	,035	,435	5,319	1	,021
(Scale)	1[a]						
(Negative binomial)	1[a]						

Dependent Variable: ongevallen
Model: (Intercept), PIARC, offset = LN_TOT2_INT

a. Fixed at the displayed value.

Appendix E: Example of the binomial logistic distribution model

SPSS results of a binomial logistic distribution model: Influence of conflict points, bicycle flow, car flow on the possibility if a crash can happen at an intersection.

Logistic Regression

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	50	100,0
	Missing Cases	0	,0
	Total	50	100,0
Unselected Cases		0	,0
Total		50	100,0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
,00	0
1,00	1

Block 0: Beginning Block

Classification Table[a,b]

Observed			Predicted		
			Crash		Percentage Correct
			,00	1,00	
Step 0	Crash	,00	26	0	100,0
		1,00	24	0	,0
	Overall Percentage				52,0

a. Constant is included in the model.

b. The cut value is ,500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	-,080	,283	,080	1	,777	,923

Variables not in the Equation

			Score	df	Sig.
Step 0	Variables	Conflictpunten	2,081	1	,149
		LN_MVT_INT	8,937	1	,003
		LN_FTS_INT	17,119	1	,000
	Overall Statistics		17,148	3	,001

Block 1: Method = Enter

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	20,390	3	,000
	Block	20,390	3	,000
	Model	20,390	3	,000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	48,845[a]	,335	,447

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than ,001.

Classification Table[a]

			Predicted		
			Crash		Percentage Correct
	Observed		,00	1,00	
Step 1	Crash	,00	16	10	61,5
		1,00	7	17	70,8
	Overall Percentage				66,0

a. The cut value is ,500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Conflictpunten	,002	,009	,059	1	,807	1,002
	LN_MVT_INT	-,147	,489	,091	1	,763	,863
	LN_FTS_INT	1,050	,403	6,782	1	,009	2,858
	Constant	-3,994	3,250	1,510	1	,219	,018

a. Variable(s) entered on step 1: Conflictpunten, LN_MVT_INT, LN_FTS_INT.

Appendix F: Results conflict points

In the following tables the results of the conflict points method are given.

Table 16: Conflict Points with traffic signals

KPID	Car vs Car	Car vs PT	Car vs Bike	Car vs Pedestrian	PT vs PT	PT vs Bike	PT vs Pedestrian	Bike vs Bike	Bike vs Pedestrian	Total
790	51	-	27	22	-	-	-	7	7	114
1028	6	-	10	9	-	-	-	6	8	39
1039	37	14	23	9	0	4	2	8	6	103
1070	51	16	29	16	0	4	4	12	8	140
1072	65	-	24	16	-	-	-	3	5	113
1130	19	10	17	14	0	4	4	12	8	88
1143	24	38	20	13	14	14	13	8	8	152
1204	16	4	22	8	0	4	2	9	6	71
1215	50	16	26	20	0	4	4	12	8	140
1220	3	11	13	6	2	9	5	12	6	67
1223	24	14	36	12	0	8	4	16	10	124
1254	24	40	34	15	14	20	14	12	8	181
1268	51	-	25	15	-	-	-	12	8	111
1279	0	7	4	4	0	2	2	3	4	26
1336	9	10	20	13	0	6	4	13	8	83
1370	51	-	26	14	-	-	-	12	7	110
1389	14	-	20	9	-	-	-	7	4	54
1405	69	-	39	19	-	-	-	46	11	184
1453	14	-	15	7	-	-	-	12	6	54
1480	7	5	13	12	0	4	4	7	6	58
1484	24	6	13	14	0	4	4	18	10	93
1497	6	4	12	5	0	4	2	6	6	45
1514	24	12	15	11	0	4	4	12	8	90
1557	24	-	16	8	-	-	-	12	8	68
1562	29	12	20	13	0	4	4	12	8	102

Table 17: Conflict Points with traffic signals and without speed reduction

KPID	Car vs Car	Car vs PT	Car vs Bike	Car vs Pedestrian	PT vs PT	PT vs Bike	PT vs Pedestrian	Bike vs Bike	Bike vs Pedestrian	Total
790	41	-	12	12	-	-	-	7	6	78
1028	4	-	4	4	-	-	-	6	6	24
1039	30	14	9	6	0	4	2	8	4	77
1070	41	16	13	12	0	4	4	12	8	110
1072	51	-	13	15	-	-	-	2	4	85
1130	17	10	8	8	0	4	4	12	8	71
1143	20	27	8	8	12	6	6	6	8	101
1204	8	4	5	2	0	4	2	8	5	38
1215	40	16	12	12	0	4	4	12	8	108
1220	3	8	8	4	2	4	2	8	4	43
1223	20	14	16	8	0	8	4	16	8	94
1254	20	30	12	8	12	6	6	12	8	114
1268	41	-	12	13	-	-	-	12	8	86
1279	0	6	3	3	0	0	0	3	3	18
1336	7	10	6	6	0	6	4	13	8	60
1370	41	-	12	10	-	-	-	12	6	81
1389	10	-	6	3	-	-	-	7	4	30
1405	54	-	25	11	-	-	-	36	8	134
1453	11	-	8	4	-	-	-	11	5	39
1480	5	2	4	4	0	0	0	6	5	26
1484	20	6	6	8	0	4	4	16	8	72
1497	4	4	4	2	0	4	2	5	4	29
1514	20	12	8	8	0	4	4	12	8	76
1557	20	-	8	8	-	-	-	12	8	56
1562	25	12	10	9	0	4	4	11	7	82

Table 18: Conflict Points without traffic signals

KPID	Car vs Car	Car vs PT	Car vs Bike	Car vs Pedestrian	PT vs PT	PT vs Bike	PT vs Pedestrian	Bike vs Bike	Bike vs Pedestrian	Total
122	24	-	10	4	-	-	-	11	6	55
141	24	-	29	-	-	-	-	19	-	72
229	0	-	4	2	-	-	-	6	2	14
253	18	-	24	11	-	-	-	16	11	80
288	24	-	29	4	-	-	-	14	4	75
313	3	-	8	3	-	-	-	6	4	24
332	6	-	4	0	-	-	-	0	0	10
334	6	-	12	3	-	-	-	6	2	29
529	6	-	10	2	-	-	-	13	2	33
542	24	-	52	6	-	-	-	24	6	112
638	6	-	4	-	-	-	-	0	-	10
644	0	-	5	2	-	-	-	7	2	16
681	14	-	11	6	-	-	-	4	6	41
722	6	-	12	7	-	-	-	6	7	38
736	6	-	12	3	-	-	-	6	3	30
767	6	-	12	4	-	-	-	6	4	32
997	6	-	13	2	-	-	-	9	4	34
1004	15	-	32	2	-	-	-	27	5	81
1012	12	-	18	8	-	-	-	13	11	62
1172	24	-	22	6	-	-	-	12	6	70
1179	14	8	22	8	0	6	4	17	10	89
1199	2	-	8	4	-	-	-	6	6	26
1310	2	4	12	7	0	4	4	12	11	56
1320	0	-	3	3	-	-	-	3	4	13
1413	2	2	4	2	0	0	0	2	2	14

Table 19: Conflict Points without traffic signals and without speed reduction

KPID	Car vs Car	Car vs PT	Car vs Bike	Car vs Pedestrian	PT vs PT	PT vs Bike	PT vs Pedestrian	Bike vs Bike	Bike vs Pedestrian	Total
122	20	-	10	4	-	-	-	8	2	44
141	20	-	12	-	-	-	-	16	-	48
229	0	-	2	1	-	-	-	4	2	9
253	16	-	14	6	-	-	-	10	5	51
288	20	-	12	4	-	-	-	12	4	52
313	2	-	2	0	-	-	-	4	0	8
332	4	-	0	0	-	-	-	0	0	4
334	4	-	4	2	-	-	-	4	2	16
529	4	-	8	2	-	-	-	8	1	23
542	20	-	24	6	-	-	-	24	6	80
638	4	-	0	-	-	-	-	0	-	4
644	0	-	4	2	-	-	-	7	2	15
681	12	-	6	4	-	-	-	2	4	28
722	4	-	4	2	-	-	-	4	2	16
736	4	-	4	2	-	-	-	4	2	16
767	4	-	4	0	-	-	-	4	0	12
997	4	-	7	2	-	-	-	8	2	23
1004	7	-	9	2	-	-	-	21	2	41
1012	8	-	6	4	-	-	-	6	4	28
1172	20	-	12	6	-	-	-	12	6	56
1179	12	8	10	6	0	6	4	15	8	69
1199	1	-	4	2	-	-	-	4	2	13
1310	2	4	8	4	0	4	4	12	8	46
1320	0	-	2	2	-	-	-	3	3	10
1413	2	2	2	1	0	0	0	2	1	10

Appendix G: Results PIARC

The following tables show the results of the PIARC method.

Table 20: Main PIARC scores with traffic signals

KPID	Time to Respond	Adjust Speed	Steering of Maneuvers	Total Score
790	4.5	3	4	11.5
1028	5.33	3	4	12.33
1039	3.5	2.75	3.5	9.75
1070	5	3	3.5	11.5
1072	4.5	2.75	4.5	11.75
1130	4.25	3	3.5	10.75
1143	4.5	3.25	3	10.75
1204	4	3	4	10.67
1215	4.75	3	3.25	11
1220	4.67	3.67	3.33	11.67
1223	4.5	3.5	3.75	11.75
1254	4	3.5	3	10.5
1268	5	3	4	12
1279	5	3.67	3.67	12.33
1336	3.5	3	3.5	10
1370	4.75	3.5	4.25	12.5
1389	3.67	3	4.33	11
1405	4	3	4.25	11.25
1453	4.33	3	4.33	11.67
1480	4.33	3.33	3.33	11
1484	4.25	3.5	3	10.75
1497	5.33	3.33	3.67	12.33
1514	4.25	3.5	3.5	11.25
1557	4.75	4	4	12.75
1562	4	3	3.25	10.25

Table 21: PIARC characteristic with traffic signals

KPID	Lighting	Traffic Signals	Speed control	Signage	Priority arrangement	Visibility triangle	Distinction Hardening	Direction Choice	Driving direction separation	Horizontal alignment	Zebra	Bicycle facilities	Field of View	Bus/Tram Facilities
790	2	1	0	0	1	0.5	0	1	1	0	1	1	2	0
1028	2	1	0	0	1	1.33	0	1	1	0	1	1	2	0
1039	1.75	1	0	1	1	0.5	0	1	1	1	1	1	1.5	1
1070	2	1	0	0	1	1	0	1	1	0	1	1	2	1
1072	1.5	1	0	0	1	1	0	1	1	0	1	1	2	0
1130	2	1	0	0	1	0.25	0	1	1	0	1	1	2	1
1143	2	1	0	0	1	0.5	0	1	1	0	1	1	2	1
1204	2	1	0	0	1	0	0	1	1	0	1	1	2	1
1215	2	1	0	0	1	0.5	0	1	1	0	1	1	1.75	1
1220	2	1	0	1	1	1.33	0	0	1	0	1	1	2	1
1223	1.75	1	0	0	1	0.25	0	0	1	0	1	1	2	1
1254	2	1	0	0	1	0	0	1	1	0	1	1	2	1
1268	2	1	0	0	1	1	0	1	1	0	1	1	2	0
1279	2	1	0	0	0	0.67	0	0	0	1	1	1	2	1
1336	2	1	0	1	1	0	0	1	1	0	1	1	2	1
1370	2	1	0	0	1	0.75	0	1	1	0	1	1	2	0
1389	2	1	0	1	1	0	0	1	1	0	1	1	2	0
1405	2	1	0	0	1	0	0	1	1	0	1	1	2	0
1453	2	1	0	0	1	0.33	0	1	1	0	1	1	2	0
1480	2	1	0	0	1	0.33	0	1	1	0	1	1	2	1
1484	2	1	0	0	1	0.25	0	1	1	0	1	1	2	1
1497	2	1	0	0	1	1	0	1	1	0	1	1	2	1
1514	2	1	0	0	1	0.25	0	1	1	0	1	1	2	1
1557	2	1	0	0	1	0.75	0	0	0	1	1	1	2	0
1562	1.75	1	0	0	1	0.25	0	1	1	0	1	1	2	1

Table 22: Main PIARC scores without traffic signals

KPID	Time to Respond	Adjust Speed	Steering of Maneuvers	Total Score
122	7.25	3.5	5	15.75
141	5.25	2.5	5.25	13
229	6	3	7	16
253	5.5	3	5.25	13.75
288	6.25	3	5.75	15
313	6.33	3.33	6.67	16.33
332	7	3	7	17
334	6.33	3.67	6.33	16.33
529	5.33	4	4.67	14
542	5.25	3.25	6.5	15
638	6.67	3.33	5	15
644	6.33	3.33	5.67	15.33
681	5.5	3	5.25	13.75
722	6	2.67	6.33	15
736	5	3	6	14
767	6	3	6	15
997	5.67	3.33	5.67	14.67
1004	6	3.67	5	14.67
1012	6	3.5	5	14.5
1172	6.75	3	5.75	15.5
1179	5	3.5	4.25	12.75
1199	6	3.33	6.33	15.67
1310	5.25	3.5	4	12.75
1320	6.5	3.75	6.25	16.5
1413	7	2.67	5.33	15

Table 23: PIARC characteristics without traffic signals

KPID	Lighting	Traffic Signals	Speed control	Signage	Priority arrangement	Visibility triangle	Distinction Hardening	Direction Choice	Driving direction separation	Horizontal alignment	Zebra	Bicycle facilities	Field of View	Bus/Tram Facilities
122	1.75	0	0	0	1	2	0	0	1	0	0	1	2	0
141	0.75	0	0	0	1	1.25	0	0	0	1	0	1	2	1
229	1	0	0	0	0	1	0	0	0	0	0	0	2	0
253	1.5	0	0	0	1	1	0	1	1	0	0	1	2	0
288	1.25	0	0	0	1	1.75	0	0	0	1	0	1	2	0
313	1.33	0	0	0	0	1	0	0	0	0	0	0	2	0
332	1.33	0	0	0	0	2	0	0	0	0	0	0	2	0
334	1.67	0	0	0	0	0.67	0	0	0	1	0	0	2	0
529	2	0	1	0	1	1	0	0	0	1	0	1	2	0
542	1.25	0	0	0	1	1	0	0	0	0	0	0	2	0
638	2	0	0	0	1	1.67	0	1	1	0	0	1	2	0
644	1.67	0	0	0	0	1	0	0	1	0	0	1	2	0
681	1.5	0	0	0	1	1	1	0	1	0	0	1	2	1
722	1	0	0	0	0	1	0	0	0	1	0	0	2	0
736	1	0	0	0	0	0	0	0	0	1	0	0	2	0
767	1	0	0	0	0	1.33	0	0	0	1	0	0	2	0
997	1.67	0	0	0	1	1	0	0	0	1	0	1	2	0
1004	1.67	0	0	0	1	1.33	0	0	1	0	0	1	2	0
1012	1.75	0	0	0	1	1.25	0	0	1	0	0	1	2	0
1172	1.5	0	1	0	0	2	1	0	1	0	0	1	2	0
1179	1.75	0	1	0	1	0.75	0	0	1	0	1	1	2	1
1199	1.33	0	0	0	0	0.67	0	0	0	1	0	0	2	0
1310	2	0	1	0	1	0.25	1	0	1	0	1	1	2	1
1320	2	0	0	0	0	0.75	0	0	0	0	0	1	2	0
1413	1.67	0	0	0	0	1.33	0	1	1	0	0	1	2	0

Appendix H: Other results

Table 24 and Table 25 show the other results acquired of the intersections. Number of ways, whether an intersection is a 3 way or a 4-way intersection. Bicycle crashes, whether bicycle crashes occurred (1) or not (0) at the intersection. Severe1, whether bicycle crashes resulting in light wounded people occurred (1) or not (0) at the intersection. Severe2, whether bicycle crashes resulting in hospitalized people occurred (1) or not (0) at the intersection.

Table 24: Other results with traffic signals

KPID	Number of Ways	Bicycle Crashes	Light wounded	Hospitalized
790	4	1	1	1
1028	3	0	0	0
1039	4	0	0	0
1070	4	1	0	0
1072	4	0	0	0
1130	4	1	1	1
1143	4	1	1	1
1204	3	1	1	1
1215	4	0	0	0
1220	3	0	0	0
1223	4	1	1	0
1254	4	1	1	1
1268	4	0	0	0
1279	3	1	1	1
1336	4	1	1	1
1370	4	0	0	0
1389	3	1	1	1
1405	4	0	0	0
1453	3	1	1	1
1480	3	1	1	1
1484	4	0	0	0
1497	3	0	0	0
1514	4	1	1	0
1557	4	1	1	1
1562	4	1	1	1

Table 25: Other results without traffic signals

KPID	Number of Ways	Bicycle Crashes	Light wounded	Hospitalized
122	4	0	0	0
141	4	0	0	0
229	3	0	0	0
253	4	1	0	0
288	4	0	0	0
313	3	0	0	0
332	3	0	0	0
334	3	0	0	0
529	3	1	1	1
542	4	1	1	1
638	3	0	0	0
644	3	1	1	0
681	4	1	0	0
722	3	0	0	0
736	3	0	0	0
767	3	0	0	0
997	3	0	0	0
1004	3	0	0	0
1012	4	0	0	0
1172	4	1	1	1
1179	4	1	1	1
1199	3	0	0	0
1310	4	1	1	1
1320	4	1	1	1
1413	3	0	0	0

Appendix I: Results negative binomial distribution models

The following table shows the results of the negative binomial distributions. Each parameter was put in the model on themselves, with the offset variable of $\ln(Flow_{Car} * Flow_{Bicycle})$. The first row of each parameter shows the results of the parameter itself. The second row shows the results of the intercept of that parameter. With these results the amount of crashes can be calculated with the following equation:

$$Crashes = B_{intercept} + B_{parameter} * Score_{parameter} + \ln(Flow_{Car} * Flow_{Bike})$$

Table 26: Parameter estimates Conflict Points

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	p
Total Conflict Points	-0.004	0.004	-0.012	0.005	0.812	1	0.368
Intercept Total Conflict Points	-13.967	0.443	-14.836	-13.099	993.027	1	<0.001
Total Bicycle Conflict Points	-0.003	0.014	-0.030	0.023	0.065	1	0.799
Intercept Total Bicycle Conflict Points	-14.142	0.620	-15.358	-12.926	519.765	1	<0.001
Bicycle vs Car Conflict points	0.000	0.027	-0.053	0.054	<0.001	1	0.993
Intercept Bicycle vs Car Conflict points	-14.286	0.57	-15.403	-13.169	628.251	1	<0.001
Total Conflict Points, without speed reduction	-0.006	0.007	-0.019	0.007	0.757	1	0.384
Intercept Total Conflict Points, without speed reduction	-13.955	0.468	-14.873	-13.037	887.628	1	<0.001
Total Bicycle Conflict Points, without speed reduction	-0.004	0.022	-0.048	0.039	0.039	1	0.843
Intercept Total Bicycle Conflict Points, without speed reduction	-14.164	0.659	-15.451	-12.876	165.060	1	<0.001
Bicycle vs Car Conflict Points, without speed reduction	0.009	0.067	-0.122	0.139	0.017	1	0.897
Intercept Bicycle vs Car Conflict Points, without speed reduction	-14.350	0.599	-15.523	-13.177	574.924	1	<0.001

Table 27: Parameter estimates PIARC

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	p
PIARC	0.235	0.102	0.035	0.435	5.319	1	0.021
Intercept PIARC	-17.175	1.327	-19.776	-14.573	167.488	1	<0.001
Time to Respond	0.317	0.242	-0.157	0.791	1.719	1	0.190
Intercept Time to Respond	-15.815	1.198	-18.164	-13.467	174.214	1	<0.001
Adjust Speed	0.963	0.692	-0.393	2.318	1.938	1	0.164
Intercept Adjust Speed	-17.475	2.324	-22.030	-12.920	56.533	1	<0.001
Steering of Maneuvers	0.530	0.154	0.230	0.831	11.948	1	0.001
Intercept Steering of Maneuvers	-16.487	0.718	-17.895	-15.079	526.618	1	<0.001
Lighting	-1.770	0.709	-3.160	-0.380	6.225	1	0.013
Intercept Lighting	-10.929	1.258	-13.394	-8.463	75.491	1	<0.001
Visibility triangle	0.104	0.466	0.808	1.017	0.050	1	0.823
Intercept Visibility triangle	-14.339	0.295	-14.918	-13.761	2358.061	1	<0.001
Field of View	-	-	-	-	-	-	-
Intercept Field of View	-	-	-	-	-	-	-
Traffic Signals (Absent)	1.280	0.358	0.579	1.981	12.807	1	<0.001
Intercept Traffic Signals	-14.732	0.243	-15.209	-14.256	3665.961	1	<0.001
Speed Control (Absent)	-0.881	0.297	-1.462	-0.300	8.835	1	0.003
Intercept Speed Control	-13.530	0.141	-13.809	-13.251	9021.024	1	<0.001
Signage (Absent)	0.025	0.614	-1.179	1.229	0.002	1	0.968
Intercept Signage	-14.302	0.567	-15.414	-13.190	635.420	1	<0.001
Priority arrangement (Absent)	1.030	0.466	0.117	1.944	4.886	1	0.027
Intercept Priority arrangement	-14.471	0.216	-14.895	-14.047	4472.182	1	<0.001
Distinction hardening (Absent)	-1.013	0.308	-1.617	-0.410	10.826	1	0.001
Intercept Distinction hardening	-13.361	0.193	-13.739	-12.984	4809.419	1	<0.001
Direction choice (Absent)	1.169	0.386	0.413	1.926	9.178	1	0.002
Intercept Direction choice	-14.782	0.290	-15.351	-14.214	2598.485	1	<0.001
Driving direction separation (Absent)	1.294	0.429	0.454	2.134	9.109	1	0.003
Intercept Driving direction separation	-14.528	0.219	-14.958	-14.099	4391.753	1	<0.001
Horizontal alignment (Absent)	-0.067	0.426	-0.768	0.901	0.025	1	0.876
Intercept Horizontal alignment	-14.341	0.351	-15.030	-13.652	1664.748	1	<0.001
Zebra (Absent)	1.210	0.371	0.483	1.936	10.651	1	0.001
Intercept Zebra	-14.581	0.206	-14.985	-14.176	4993.430	1	<0.001
Bicycle facilities (Absent)	1.693	0.335	1.037	2.349	25.579	1	<0.001
Intercept Bicycle facilities	-14.342	0.216	-14.765	-13.918	4408.679	1	<0.001
Bus/Tram facilities (Absent)	0.300	0.470	-0.623	1.222	0.405	1	0.524
Intercept Bus/Tram facilities	-14.392	0.221	-14.826	-13.959	4232.243	1	<0.001

Appendix J: Results binomial logistic distribution models

The following tables show the results of the binomial logistic distributions. Each table shows the results of all the variables that were considered for that model.

Table 28: Variables in the equation bicycle crash by Conflict points

Variable	B	S.E.	Wald	df	p	Exp (B)
Conflict points	0.002	0.009	0.059	1	0.807	1.002
Car flow	-0.147	0.489	0.091	1	0.763	0.863
Bicycle flow	1.050	0.403	6.782	1	0.009	2.858

Table 29: Variables in the equation bicycle crash by PIARC

Variable	B	S.E.	Wald	df	p	Exp (B)
PIARC	0.094	0.258	0.132	1	0.716	1.098
Car flow	0.006	0.542	<0.001	1	0.990	1.006
Bicycle flow	1.057	0.403	6.887	1	0.009	2.879

Table 30: Variables in the equation bicycle crash by Conflict points and PIARC

Variable	B	S.E.	Wald	df	p	Exp (B)
Conflict points	0.005	0.010	0.266	1	0.606	1.005
PIARC	0.177	0.306	0.336	1	0.562	1.194
Car flow	-0.012	0.552	0.001	1	0.982	0.988
Bicycle flow	1.106	0.419	6.966	1	0.008	3.023

Table 31: Variables in the equation light wounded by Conflict points

Variable	B	S.E.	Wald	df	p	Exp (B)
Conflict points	<0.001	0.009	0.001	1	0.970	1.000
Car flow	-0.256	0.585	0.192	1	0.662	0.774
Bicycle flow	1.491	0.556	7.193	1	0.007	4.440

Table 32: Variables in the equation light wounded by PIARC

Variable	B	S.E.	Wald	df	p	Exp (B)
PIARC	0.197	0.293	0.451	1	0.502	1.218
Car flow	-0.014	0.676	<0.001	1	0.984	0.987
Bicycle flow	1.559	0.576	7.317	1	0.007	4.755

Table 33: Variables in the equation Light wounded by Conflict points and PIARC

Variable	B	S.E.	Wald	df	p	Exp (B)
Conflict points	0.004	0.011	0.150	1	0.699	1.004
PIARC	0.267	0.347	0.592	1	0.442	1.306
Car flow	-0.009	0.683	<0.001	1	0.989	0.991
Bicycle flow	1.613	0.602	7.185	1	0.007	5.020

Table 34: Variables in the equation hospitalized by Conflict points

Variable	B	S.E.	Wald	df	p	Exp (B)
Conflict points	-0.001	0.009	0.027	1	0.869	0.999
Car flow	0.146	0.587	0.062	1	0.804	1.157
Bicycle flow	1.124	0.484	5.399	1	0.020	3.078

Table 35: Variables in the equation hospitalized by PIARC

Variable	B	S.E.	Wald	df	p	Exp (B)
PIARC	0.176	0.280	0.397	1	0.529	1.193
Car flow	0.362	0.690	0.275	1	0.600	1.436
Bicycle flow	1.186	0.497	5.689	1	0.017	3.275

Table 36: Variables in the equation Hospitalized by Conflict points and PIARC

Variable	B	S.E.	Wald	df	p	Exp (B)
Conflict points	0.002	0.010	0.049	1	0.825	1.002
PIARC	0.217	0.335	0.419	1	0.518	1.242
Car flow	0.366	0.692	0.280	1	0.597	1.442
Bicycle flow	1.217	0.521	5.455	1	0.020	3.377