FACTORS THAT INFLUENCE THE SEVERITY OF CONFLICTS AT SIGNALISED INTERSECTIONS

Bachelor Thesis Civil Engineering
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WETENSCHAPPELIJK ONDERZOEK VERKEERSVEILIGHEID

PREFACE

Dear reader,

In front of you lies my bachelor thesis report which is the completion of my bachelor study in Civil Engineering at the University of Twente. In this bachelor thesis, all the knowledge I obtained during the past few years of studying is combined to do research on which factors influence the severity of conflicts at signalised intersections between cyclists and motorized vehicles. This research is done in collaboration with SWOV, which is a national scientific institute for road safety in the Netherlands. I hope that this research is useful to get a better understanding of which factors influence the severity of conflicts at signalised intersections. Furthermore, I hope that SWOV can benefit from this study when continuing to study traffic safety at intersections.

While making this bachelor thesis I realised that road safety is influenced by many interrelated factors which makes it complex to analyse exactly to what extent certain factors influence road safety. I have enjoyed the challenge of making this bachelor thesis and have learned many new things about traffic. As a result, I now look as a road user with a different perspective on traffic safety than in the past.

I would like to thank SWOV for giving me the opportunity to make my bachelor thesis within their organisation. In particular, I would like to thank Sarah Gebhard, my supervisor at SWOV, for her support and feedback while making this bachelor thesis report. Furthermore, I also want to thank Matin Nabavi Niaki of SWOV, who helped me with my bachelor thesis when Sarah was on holiday. I would also like to thank all the other employees of SWOV, who gave me inspiration for my bachelor thesis and helped me during the making of this research. Besides, I would also like to thank my supervisor from the University of Twente, Baran Ulak, for his guidance and feedback during the process of making this bachelor thesis. Lastly, I want to thank my family for always supporting me, giving me the opportunity to grow and for teaching me new things every day.

I hope you enjoy reading my bachelor thesis report.

Aniek Hollander

Epe, 12 June 2023

SUMMARY

In the period between 2015 and 2019, 54% of all crashes in the Netherlands in which cyclists were killed happened at intersections (SWOV, 2022). To decrease the number of crashes between cyclists and motorized vehicles at intersections, research should be done on which factors influence traffic safety at intersections. Last year, SWOV, a national scientific institute for road safety in the Netherlands, started a research project to investigate traffic safety at intersections in the Netherlands by making and analysing video footage of three intersections in the region of The Hague. The video footage made by SWOV is used in this report to research which factors influence the severity of conflicts at signalised intersections between cyclists and motorized vehicles. In this bachelor thesis, conflicts are understood as a situation where there was almost a crash, but by taking actions such as braking the crash was avoided just in time. It is chosen to look at conflicts instead of crashes in this research since more conflict data is available than crash data. Furthermore, in the literature, it is shown that conflict data is a good indicator of traffic safety.

A literature study is conducted which shows that several indicators can be used to define the severity of conflict. However, there is no consensus among researchers on which method is the most useful to determine the severity of conflicts. In some studies, the Post Encroachment Time (PET) is used to determine the severity level of a conflict. However, from this research, it can be concluded that the severity of a conflict cannot fully be determined by solely using the PET value, since it is observed in the video data of SWOV that sometimes the PET value is low while the conflict is not severe. Therefore, it is chosen in this research to create a method inspired by the Dutch Traffic Conflict Technique to determine the severity of conflicts based on the possibility that the conflict will develop into a collision and the potential conflict consequences.

Furthermore, a literature review is done which shows that a lot of factors can influence the severity of conflicts at intersections such as intersection design, human factors, environment, and vehicle speed. However, in this research limited data is available which makes it difficult to examine all factors that can influence the severity of conflicts at signalised intersections. For instance, based on the available data nothing can be said about the influence of intersection design on the severity of conflicts at intersections. The factors that can be observed from the video footage are factors such as vehicle speed, traffic intensity, time of day, light intensity, cycling in groups, type of cyclist, traffic offences, who breaks the traffic rules and who goes first (cyclist or motorized vehicle). Around 300 conflicts are watched from the video footage and for all these conflicts information is recorded about the factors that can possibly influence the severity of the conflict. Subsequently, this data obtained from the video footage is analysed with the help of descriptive statistics and a multinomial logistic regression model. Based on this analysis it can be concluded that the factors ‘motorized vehicle speed’, ‘cycling alone’, 'cyclist from standstill', 'type of cyclist' and 'red light violation cyclist' influence the severity level of conflicts between cyclists and motorized vehicles at signalised intersections. Furthermore, it can be concluded that more data is needed to determine whether other factors also have an impact on conflict severity.

Therefore, it is recommended to obtain more video footage from different view angles for different intersections to examine which other factors have a significant effect on the severity of conflicts at signalised intersections between cyclists and motorized vehicles. Besides, it is recommended to watch more video footage to decrease the uncertainty of the research.

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1. INTRODUCTION

1.1. PROBLEM CONTEXT

Currently, there are approximately 1.35 million deaths worldwide per year in road traffic according to the World Health Organisation (World Health Organisation, 2018). According to research, traffic deaths will be the fifth most common cause of death by 2030 (Xiao, Jin, Xu, Ma, & Yuan, 2021). However, Sustainable Development Goal 3.6 of the UN is to halve the number of global deaths and injuries due to road crashes (United Nations, 2023). In the Netherlands, it is chosen to follow the international goal to halve the number of fatal crashes in traffic by 2030 (Tweede Kamer, 2021). In the Netherlands, there were 582 deaths in traffic in 2021 (SWOV, 2022). Around one-third of these people killed in traffic crashes in the Netherlands are killed at intersections (SWOV, 2022). Especially the number of cyclists that are killed at intersections is relatively high. In the period between 2015 and 2019, 54% of all the crashes in which cyclists were killed happened at intersections (SWOV, 2022). Therefore, it is needed to research traffic safety at intersections to decrease the number of crashes at intersections and to reach Sustainable Development Goal 3.6 and the goal of the Netherlands to halve the number of fatal crashes.

Researchers often use conflict data instead of crash data when analysing traffic safety at intersections, where conflicts are interpreted as situations where a collision could just be avoided by taking actions such as braking (Chin & Quek, 1997). Often conflict data is used instead of crash data since conflict data can be collected in a shorter time frame than crash data. Therefore, conflicts are often more suitable to gain insight into safety concerns at intersections (Alhajyaseen, 2014). Conflicts can be measured with for instance the Time-To-Collision and Post Encroachment Time methods. However, these measures do not fully represent the severity of conflicts according to some researchers ((Alhajyaseen, 2014); (Jiang, et al., 2020)). Therefore, some researchers use other methods such as the Dutch Traffic Conflict Technique (Kraay & van der Horst, 1985) and the Conflict Index (Alhajyaseen, 2014) to identify the severity of conflicts.

In the past decades, a lot of research has been done on which factors influence the severity of conflicts at intersections between cyclists and motorized vehicles. However, most of these studies are done outside the Netherlands and the cycling infrastructure in the Netherlands is in general quite developed compared to other parts of the world. This is partly related to the fact that the Dutch population has the most cyclists in the world, 99.1% of the whole Dutch population cycles (Kennisdomein, 2022). Since the cycling infrastructure in the Netherlands differs from other parts of the world it is important to also do research in the Netherlands on which factors have an impact on traffic safety at intersections. Furthermore, there is no consensus yet between researchers on which factors influence the severity of conflicts. For instance, there is no consensus on the exact relationship between traffic intensity and the severity of conflicts (Retallack & Ostendorf, 2020). Therefore, it needs to be investigated which factors influence the severity of conflicts in the Netherlands.

Last year, SWOV (Stichting Wetenschappelijk Onderzoek Verkeersveiligheid), a national scientific institute for road safety in the Netherlands, started a research project to investigate traffic safety at intersections in the Netherlands. SWOV did a pilot study last year in which they gathered video footage at intersections to get a better insight into traffic safety at intersections. SWOV gathered video data at three intersections in the region of The Hague. This video footage is subsequently analysed with computer software. This software indicates where conflicts happen, the type of vehicles involved in the conflict and the direction of the vehicles. Furthermore, the software also gives the Time-To-Collision (TTC) and Post Encroachment Time (PET). In this bachelor thesis, the data obtained in the pilot study done by SWOV is used.

1.2. RESEARCH GAP

As mentioned in the problem context (see Paragraph 1.1), it is needed to investigate what factors influence traffic safety at intersections in the Netherlands to improve traffic safety and hence decrease the number of crashes. It is especially important to investigate traffic safety at intersections between cyclists and motorized vehicles since a lot of cyclists are involved in fatal crashes at intersections (SWOV, 2022). Currently, not a lot of information is available on factors that influence the traffic safety of cyclists at signalised intersections in the Netherlands. To get an insight into which factors influence traffic safety at signalised intersections, research should be done on how certain factors influence the severity of conflicts. It is important to look at the severity of conflicts since the main goal of the United Nations and the Netherlands is to reduce the conflicts and hence crashes with the most severe consequences (death and injuries). However, as mentioned in the problem context, there is no consensus among researchers on how to determine the severity of a conflict. Therefore, it is also needed to investigate how the severity level of conflicts can be determined.

1.3. RESEARCH OBJECTIVE

As discussed in the problem context and the paragraph about the research gap (see Paragraphs 1.1 and 1.2), more research is needed on factors that influence the severity of conflicts at intersections between cyclists and motorized vehicles. Therefore, the research objective is to analyse what kind of factors influence the severity of conflicts between cyclists and motorized vehicles at signalised intersections.

1.4. RESEARCH QUESTIONS

In this paragraph, the research questions for reaching the research objective described above (see Paragraph 1.3) are listed. The main question is:

Main question: What kind of factors influence the severity of conflicts between cyclists and motorized vehicles at signalised intersections?

To answer this main question, first of all, it should be determined how the severity of conflict at signalised intersections can be measured. Since the data obtained by SWOV includes information on the PET and TTC, it should be determined how the TTC or PET can be used to classify the severity of conflicts. Therefore, subquestion 1 is:

Subquestion 1: How can the severity of conflicts at signalised intersections be classified by using TTC or PET?

Secondly, after subquestion 1 is answered it should be determined what factors influence the severity of conflicts at intersections. Therefore, subquestion 2 is:

Subquestion 2: What factors influence the severity of conflicts at signalised intersections?

When both these two questions have been answered, the answer to the main question can be given.

1.5. Report outline

As mentioned above, more research is needed on traffic safety at intersections and especially on safety between cyclists and motorised vehicles. The main data used in this research is video footage obtained by SWOV at three intersections in The Hague. Therefore, in the next chapter, it is explained which parties are involved in the research, what the research area is, and which data is available. Secondly, a literature review is done in Chapter 3 to get an insight into what research has been done in the past decades on which factors influence the severity of conflicts at intersections. Subsequently, in Chapter 4, a methodology is given based on the literature review to answer the research questions. After that, the results of this research are given in Chapter 5 followed by a discussion in Chapter 6. Lastly, the recommendations are given in Chapter 7 followed by the conclusion in Chapter 8.

2. INVOLVED PARTIES, STUDY AREA, AND AVAILABLE DATA

As already mentioned in the introduction, this bachelor thesis is made in collaboration with SWOV, a national scientific institute of road safety in the Netherlands. Therefore, this chapter discusses what type of organisation SWOV is. Subsequently, it is explained to which project of SWOV this bachelor thesis contributes and which data from this project is used for this bachelor thesis.

2.1. INVOLVED PARTIES

This bachelor is made in collaboration with SWOV (Stichting Wetenschappelijk Onderzoek Verkeersveiligheid). SWOV is an independent national scientific institute for road safety. SWOV's goal is to make traffic safer by obtaining knowledge about traffic safety. SWOV is a non-profit organization that mainly cooperates with organizations from the public domain such as provinces and municipalities, but they also cooperate with consultancies, industry, social organizations, and international research projects. These organisations can use the knowledge of SWOV and implement it in practice.

2.2. STUDY AREA

SWOV is currently doing research on traffic safety at intersections. This research is mainly concerned with traffic safety for cyclists and pedestrians at signalised intersections. The project is currently in its starting phase. At this stage of the project, a pilot is conducted in which cameras are used on three types of signalised intersections to detect conflicts between traffic at these intersections. It is considered to use the conflict data of all these three intersections in this bachelor thesis to determine which factors influence the severity level of conflicts between cyclists and motorized vehicles. However, it turned out that the video data of the intersection between the Calandstraat and the Waldorpstraat is most suitable for this study. Therefore, this study focuses on only the intersection between the Calandstaat and the Waldorpstraat (see Figure 2). With the help of computer software, it can be detected when conflicts occur in the video footage (with the Time-To-Collision and the Post Encroachment Time method), what types of vehicles are involved in the conflict and the direction that the vehicles involved in the conflict are driving. However, the severity and the cause of the conflicts cannot be determined by the software. In the coming months, SWOV is also going to make video observations at 8 other intersections. The three observed intersections in the pilot study are located in the region of The Hague and are different in size. The locations and types of intersections are:

1. **Mauritskade/Denneweg/Frederikstraat, Den Haag:** This is a relatively small inner-city intersection between a road with a 50 km/h limit and a one-way residential access road with a 30 km/h speed limit (see Figure 1).

Figure 1 - Mauritskade/Denneweg/Frederikstraat, Den Haag (52.086425923556114, 4.311484361360618)

2. **Calandstraat/Waldorpstraat, Den Haag:** This is a larger inner-city intersection between two 50 km/h roads (see Figure 2).

Figure 2 - Calandstraat/Waldorpstraat, Den Haag (52.06337730355295, 4.3131009309114265)

3. **Eerste Tochtweg/Zuidelijke Dwarsweg, Nieuwerkerk aan den IJssel:** This is a large intersection outside the city centre with a local speed limit of 50 km/h at the intersection and speed limits of 80 km/h, 60 km/h and 50 km/h on the branches further away (see Figure 3).

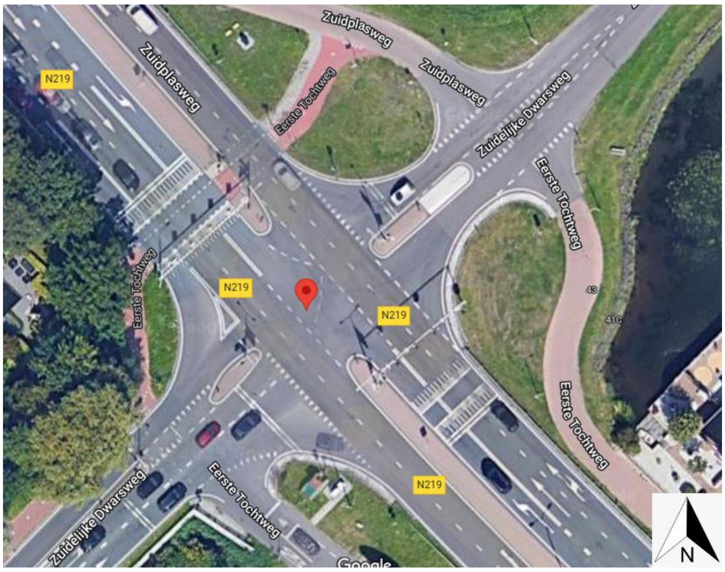

Figure 3 - Eerste Tochtweg/Zuidelijke Dwarsweg, Nieuwerkerk aan den IJssel (51.988773424175115, 4.600469993942218)

2.3. AVAILABLE DATA

As discussed in Paragraph 2.2, SWOV installed cameras at three intersections in The Hague and took video footage for one whole week (between 13 and 19 June 2022). During this week of recording, the weather conditions were good; there was a lot of sun and no rain. The recorded video footage is analysed by the software TrafxSAFE from Transoft. At the intersection of the Eerste Tochtweg, two cameras are used. However, the data of these two cameras could not be combined by the computer software TrafxSAFE. For both other intersections, the video footage of the different cameras could be combined by the software. The TrafxSAFE software makes a distinction between different types of conflicts. In Appendix A, an elaborate overview made by Transoft is shown, about the type of conflicts indicated by the software. In short, the software can determine if the interactions recorded by the cameras are interactions between two vehicles or between a vehicle and a pedestrian/cyclist. Furthermore, the program also detects the movements of the vehicles that interact with each other.

Besides information about the type of interaction, the software also gives the following information:

- The value of the safety indicator (in seconds)
- The safety indicator type (PET or TTC)
- The date (year-month-year)
- Time (hour:min:sec)
- The road user that arrived first (road user 1 or road user 2)
- The movement of road users (see Appendix A)
- The type of road users (articulated truck, bicycle, box truck, bus, motorcycle, passenger car, pedestrian, or a pick-up truck)
- The conflict speeds of the road users (km/h)
- The median speeds of the road users (km/h)
- Scenario (e.g. Eastbound Right Turn Car vs. Westside Crosswalk)

All the information found by the software TrafxSAFE is given in an Excel sheet. The amount of observed data is different for all the intersections. In Table 1, an overview is shown of the number of observations made at the intersections. A limitation of the Excel data is that it does not mention what the external effects are on the traffic situation such as weather conditions. However, this data can be obtained manually from the video footage. Furthermore, it is important to note that for every conflict only one of the two conflict indicators (PET or TTC) is available, depending on the type of conflict. The TTC is only measured for rear-end conflicts and the PET is only measured for angle conflicts. Besides, only short video clips for conflicts with a PET or TTC value below 2 seconds are available.

Table 1 - Number of conflicts observed with a PET value up to 10 seconds

Intersection	Number of observations
Calandstraat	77295
Eerste Tochtweg	Camera 1: 6374, Camera 2: 467
Mauritskade	67881

For this study, the video footage obtained at the intersection between the Calandstraat and the Waldorpstraat is used, since this data is most suitable for this study. The number of conflicts, with a PET value below 2 seconds, observed from the video footage made at the Eeste Tochtweg is limited (29 interactions). Therefore, the data of this intersection is not useful in this bachelor thesis. Besides, the software indicates a lot of situations at the Mauritskade as a conflict while in reality there is not a conflict. Therefore, it is chosen to focus on the intersection of the Calandstraat with the Waldorpstraat in this study and not on the intersections at the Eerste Tochtweg and the Mauritskade.

3. LITERATURE REVIEW

First of all, a literature review has been done to obtain information to answer the research questions as discussed in Paragraph 1.4. To answer the first subquestion "How can the severity of conflicts at signalised intersections be classified by using TTC or PET?", it is discussed in Paragraph 3.1 how conflicts can be used to predict the number of crashes at intersections. Secondly, in Paragraph 3.2, it is explained how the TTC and the PET can be used to determine the severity of a conflict. Furthermore, in Paragraph 3.3, a literature study is done on the factors that influence the severity of conflicts at intersections to answer the second subquestion "What factors influence the severity of conflicts at signalised intersections?". Lastly, in Paragraph 3.4 a theoretical framework is given.

3.1. THE RELATION BETWEEN CONFLICTS AND CRASHES

To assess safety at intersections several methods can be used. First of all, crash data can be used to evaluate the safety of an intersection. However, the use of this method is often not feasible due to shortcomings such as unavailable historical crash data or the fact that not enough data is available. A good alternative for using crash data is using conflict data since conflict data does not need such long-term measurements as compared to crash data analysis (Alhajyaseen, 2014). Another advantage of using conflict data is that conflict data helps to identify traffic safety problems proactively which can help to improve the safety of intersections before an actual incident would have happened (Polders & Brijs, 2018). Therefore, the method of using conflicts is often used to evaluate safety at intersections.

In literature, conflicts are defined as critical incidents that do not necessarily involve collisions (Chin & Quek, 1997). In general, if the number of traffic conflicts increases the number of crashes also increases (Salman & Al-Maita, 1995). According to the researcher Hauer (Hauer, 1982), the expected number of crashes can be calculated based on conflict data by multiplying the number of observed traffic conflicts and the crash conflict ratio (see Equation 3.1).

$$S = P \times N \qquad \text{Equation 3.1}$$

Where:

- S is the expected number of crashes (-)
- N is the number of observed conflicts (-)
- P is the crash-conflict ratio, the probability that a crash will be the result of a conflict (-)

Several studies have been done to find the ratio between crashes and conflicts (P) in this formula. In most of these studies, traffic conflicts are observed at several intersections over a relatively short period. These conflicts were compared to crashes that are recorded over several years. Based on these comparisons several relationships are found between the number of conflicts and crashes (Tarko, 2021). However, some researchers argue that using conflict data has limited value for analysing traffic safety since the relationship is based on conflicts which are recorded in a relatively short period, while crashes are reported over longer periods (Tarko, 2021). Furthermore, according to research, the relationship between crashes and conflicts is not always clear for all types of conflicts (Polders & Brijs, 2018).

In Figure 4, the relationship between the frequency of traffic events and nearness to collision proposed by Glauz and Migletz is shown (Glauz & Migletz, 1980). This figure also it is shown how severe these conflicts are.

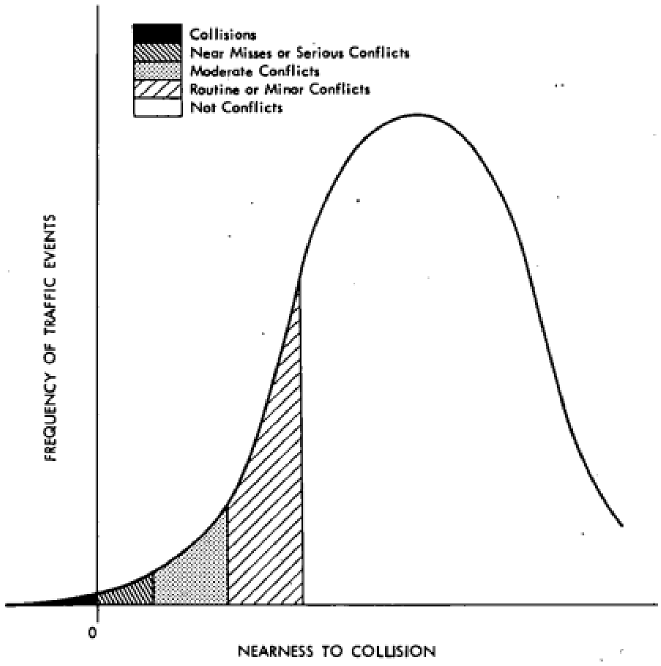

Figure 4 - Frequency distribution of traffic events (Glauz & Migletz, 1980)

There are several methods to measure conflicts. Two of the methods used most often in the literature are the Time-To-Collision (TTC) measure and the Post Encroachment Time (PET) (see Figure 5). According to researchers, the PET measure is recommended to use for angle conflicting events, while the TTC measure is more suitable for rear-end conflicting events (Alhajyaseen, 2014). In research, it is found that the PET value is one of the best conflict measures when looking at the relationship between conflicts and collision history (Allen, Shin, & Cooper, 1978). Furthermore, it is shown in research on the PET as a surrogate for opposing left-turn crashes, that the lower the PET value the stronger the relation with crashes is (Peesapati, Hunter, & Rodgers, 2013).

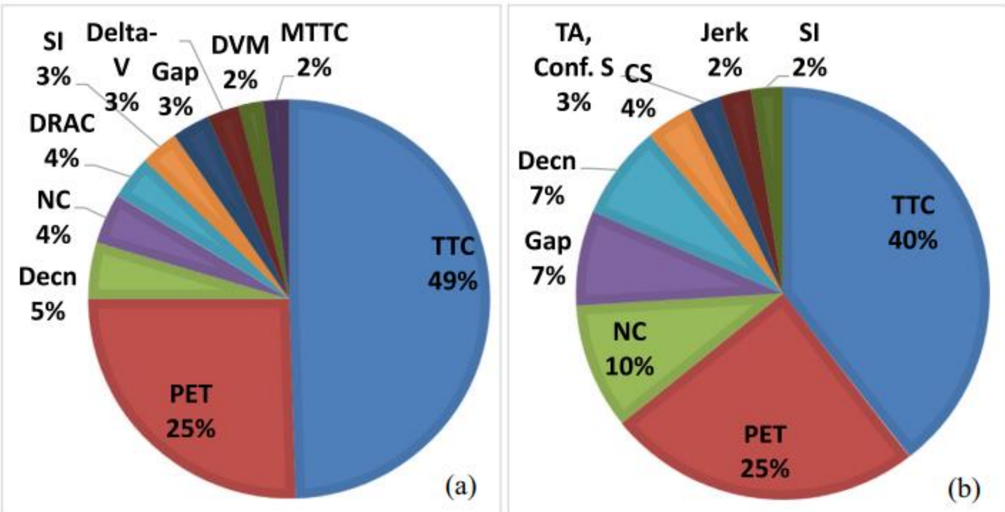

Figure 5 - Most used conflict measures in countries with (a) representing organized traffic environments and (b) representing less-organised traffic environments (Arun, Haque, Washington, Sayed, & Mannering, 2021)

The two measurements of conflicts explained above (TTC & PET) are also used in the software used by SWOV to identify conflicts from the video footage. Therefore, these two measures are further explained in the next paragraph, to investigate how useful these measurements of conflicts are to determine the severity level of conflicts.

3.2. Conflict severity using the PET and TTC

First of all, in this paragraph, a literature review is done on the TTC value (see Paragraph 3.2.1). Subsequently, a literature review is done on the PET value and how this value can be used to determine the severity of conflicts (see Paragraph 3.2.2).

3.2.1. Time-To-Collision (TTC)

The Time-To-Collision (TTC) method is defined as: 'The time that remains until a collision between two vehicles would have occurred if the collision course and speed differences are maintained' (Minderhoud & Bovy, 2000). Several researchers used the TTC to determine the severity of conflicts.

First of all, to use the TTC to determine the severity of conflicts, it should be known what levels of conflicts there are. According to research, traffic conflicts can be divided into four different levels; serious conflicts, slight conflicts, potential conflicts and undisturbed conflicts (Hydén, 1987). In Figure 6, the order of these four conflict levels is visualised. In literature about conflicts at intersections, often a reference is made to these levels of traffic conflicts described by Hydén.

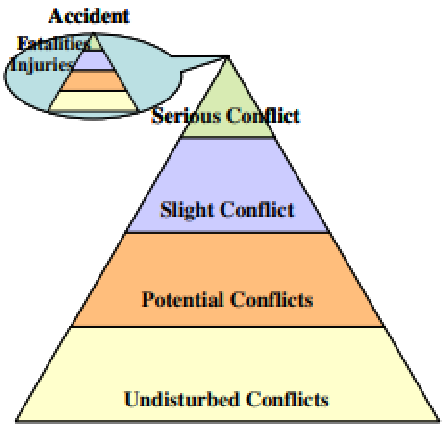

Figure 6 - Piramide of drivers' reactions (Oh, Kim, Kim, & Choo, 2009)

To determine the severity of a conflict ('serious conflict', 'slight conflict', 'potential conflict' or 'undisturbed conflicts'), two dimensions need to be considered (Jiang, et al., 2020);

1. The possibility that the conflict will develop into a collision.
2. The severity of potential conflict consequences (which is influenced by a lot of factors such as speed, vehicle quality and collision angle (Jiang, et al., 2020)).

In most studies that use the TTC as a measurement for determining the severity of conflicts, mainly the first dimension is considered and the second dimension is not always taken into account (Jiang, et al., 2020). However, the Swedish Traffic Conflict Technique indirectly reflects the severity of potential conflict consequences by using the TTC value and speed at which conflicts take place (Hydén, 1987). Furthermore, the Dutch Traffic Conflict Technique also considers the severity of potential conflict consequences (Kraay & van der Horst, 1985). This technique uses subjective scoring to evaluate the severity of conflicts. To use this technique, video data need to be observed. The observer should indicate the seriousness of the observed conflict with a rate between 1 (minor conflict) to 5 (grave conflict). The observer should take into account the risk of a collision and the potential seriousness of when a collision would have taken place. By using this method, insight can be created into the severity of conflicts. However, this method can be improved according to researchers by making it more consistent and accurate (Jiang, et al., 2020).

To determine the probability of a conflict to develop a collision in the Dutch Traffic Conflict Technique, the TTC and the PET values are used (Laureshyn, de Goede, Saunier, & Fyhri, 2016). Furthermore, the potential conflict consequences are taken into account in this method by looking at for instance speed and the type of manoeuvres that are performed. However, it should be noted that determining the consequences is quite subjective. In Figure 7, an overview is given of determining the severity of a conflict with the Dutch Traffic Conflict Technique (Laureshyn, de Goede, Saunier, & Fyhri, 2016).

Seriousness of injury	Probability of collision								
	TTC_{min}, sec.						PET, sec.		
	no TTC	>2	2–1.5	1.5–1	1.0–0.5	0.5–0	>1.0	1.0–0.5	0.5–0
very small	X	X	X	1	1	2	X	X	1
small	X	X	1	2	2/3	3	X	1	2
fairly large	X	1	2	2/3	3	4	1	2	3
large	1	2	2/3	3	4	5	2	3	4/5

Figure 7 - The severity of conflicts according to the Dutch Traffic Conflict Technique, where 1 is a minor conflict and 5 is a grave conflict (Laureshyn, de Goede, Saunier, & Fyhri, 2016)

In research different threshold values are used for the TTC to indicate a severe conflict. Since different methods, road types, situations and environments are used in studies to determine the threshold values of the TTC for a severe conflict, the threshold values used to determine severe traffic conflicts also differ between the studies. According to research, these threshold values for the TTC range from 1.0 seconds to 5.0 seconds (Jiang, et al., 2020).

3.2.2. Post Encroachment Time (PET)

The post-encroachment time is the time between when the first vehicle ends encroachment over the area of conflict and the second vehicle enters the area of conflict (Peesapati, Hunter, & Rodgers, 2018) and is often used to identify a conflict. If the PET value is 0 seconds, there is a crash. If the PET value is non-zero, this gives a crash proximity. The actions taken by the drivers are not taken into account while calculating the PET value. The PET value only provides a measure of relative closeness to a collision (Peesapati, Hunter, & Rodgers, 2018). According to researchers, the PET measure is one of the most accurate measures for analysing traffic safety at intersections (Allen, Shin, & Cooper, 1978). In literature, PET values are used within a threshold ranging between 1.0 and 6.5 seconds to indicate a severe conflict (Madhumita & Indrajit, 2019). Furthermore, a study has been done based on traffic data of Guangyuan Road in Guangzhou that describes ranges of the PET that show the severity level of a conflict (Qi, Wang, Shen, & Wu, 2020). The ranges are:

- Serious conflict: PET < 0.7 s
- General conflict: $0.7 \leq PET < 1.31$ s
- Slight conflict: $1.31 \leq PET < 2.25$ s
- Potential conflict: $PET \geq 2.25$ s

Another study that was done for intersections in Montreal also defined four PET ranges for the severity level of a conflict in which cyclists are involved (Zangenehpour, Strauss, Miranda-Moreno, & Saunier, 2015). The ranges are:

- Very dangerous interaction: $PET \leq 1.5$ s
- Dangerous interaction: $1.5 s < PET \leq 3.0$ s
- Mild interaction: $3.0 s < PET \leq 5.0$ s
- No interaction: $PET > 5.0$ s

However, the PET ranges for different severity levels differs between the two studies that are mentioned above. It should be considered that these values are determined for two different parts of the world with different road users which can cause the differences. However, no literature could be found on the categorisation of conflict severity in the Netherlands based on only the PET value. Therefore, more research should be done to look if these threshold values also hold for example in the Netherlands.

The advantages of using PET values are that the PET is directly observable; no assumptions have to be made to determine this value and it is very useful to use for conflicts with an angle between the conflicting vehicles (Arun, Haque, Washington, Sayed, & Mannering, 2021). However, using the PET measurement also has disadvantages such as the fact that the PET is expressed in only one value and does not describe further characteristics of the conflict (Arun, Haque, Washington, Sayed, & Mannering, 2021). Besides, the PET measurement is not suitable to rear-end conflicts (Alhajyaseen, 2014). In that case, the TTC is a better measuring method to use (Alhajyaseen, 2014).

As mentioned before in Paragraph 3.2.1, two dimensions need to be taken into account while determining the severity level of a conflict: the possibility that the conflict will develop a collision and the severity of potential conflict consequences (Jiang, et al., 2020). However, some researchers argue that using the PET measure is not suitable to represent the conflict probability and severity simultaneously (Alhajyaseen, 2014). According to researchers, the PET gives a good indication of the possibility that a conflict will occur, but it does not fully represent the severity of conflicts (Alhajyaseen, 2014). They argue that also other indicators need to be considered while determining the potential severity of the conflict. As can be seen in Figure 8, factors such as speed have a major impact on the severity of conflicts. Furthermore, factors such as conflict angle and the acceleration distribution of conflicting vehicles also impact the potential severity of conflicts (Alhajyaseen, 2014). According to research head-on and angle collisions increase the injury severity (Yan, Ma, Huang, Abdel-Aty, & Wu, 2011).

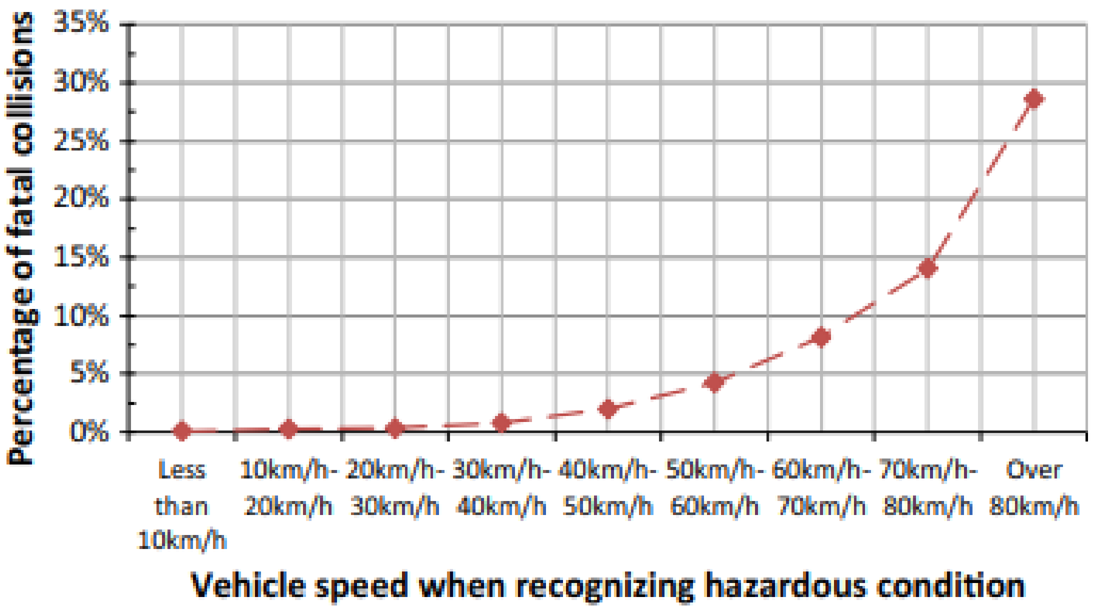

Figure 8 - Relationship between vehicle speeds in hazardous conditions and the percentage of fatal collisions based on data describing the total number of collisions on ordinary roads in Japan in 2011 (Alhajyaseen, 2014)

Therefore, research done by Alhajyaseen proposes using a Conflict Index (CI) to indicate the severity level of a crash (Alhajyaseen, 2014). This Conflict Index takes into account the potential conflict consequences by looking at the kinetic energy that would be released if a collision would occur. Furthermore, the Conflict Index uses the PET to indicate the probability that a conflict will occur. The lower the PET value the higher the probability that a collision would occur. The mathematical formulation of the Conflict Index (CI) proposed by Alhajyaseen is (Alhajyaseen, 2014):

$$CI = \frac{\alpha \Delta K_e}{e^{\beta PET}} \quad \text{Equation 3.2}$$

Where:

- CI is the severity index (kg*m^2/sec^2)
- α is the percentage of released kinetic energy that affects the people inside the vehicle (%)
- ΔK_e is the change in the total kinetic energy before and after the crash (kg*m^2/sec^{-2})
- PET is the post-encroachment time (s)
- β is an adjustment parameter that is proposed to reflect the effect of the conflict type on the collision probability (s^{-1})

Besides this study done by Alhajyaseen and the Dutch Traffic Conflict Technique, there are not a lot of other studies that use the PET measurement in combination with other factors to determine the severity of conflicts (Arun, Haque, Washington, Sayed, & Mannering, 2021). Therefore, more research is needed on what factors influence the number of conflicts at intersections and how the PET and TTC can be used to measure the severity of conflicts at intersections.

3.3. FACTORS THAT INFLUENCE THE SEVERITY OF CONFLICTS

Most cycling deaths in the Netherlands between 2015 and 2019 occurred at intersections. Inside built-up areas, an average of 60% of cycling fatalities occurred at intersections and outside built-up areas 49% of cycling fatalities occurred at intersections (SWOV, 2022). Most of these crashes happen between motorized vehicles and cyclists coming from the right side (Reurings, Vlakveld, Twisk, Dijkstra, & Wijnen, 2012). According to research, most crashes occur due to human errors. Human errors cause around 90% of crashes in traffic in the current road network (Haghi, Ghanbari, & Rajabi, 2014). Other factors that cause crashes are vehicle characteristics, road designs and the environment (Haghi, Ghanbari, & Rajabi, 2014). Therefore, the factors that influence traffic safety and are discussed in this section are; intersection design, human factors, environment, and vehicle speed.

3.3.1. Intersection design

First of all, the intersection design has an impact on safety at intersections. According to the research done by SWOV, cyclists are in general safer on roundabouts than at signalized intersections. One of the factors that affect the safety of cyclists at intersections negatively is the blind spot of lorries (Schoon, Doumen, & de Bruin, 2008). In addition, a study was done based on bicycle counts and police-reported crashes in Palo Alto that shows that cyclists on a separate bicycle path or sidewalk also have a greater risk of getting involved in a crash at intersections (1.8 times as great) than when the bicycle path or sidewalk is not separated from the main road (Wachtel & Lewiston, 1994). However, a study was also done in Amsterdam which shows that at intersections with physically separated cycling tracks from the main road, 50% to 60% fewer cycling crashes are expected than at intersections where the cycling lane is not separated from the main road (van Petegem, Schepers, & Wijlhuizen, 2020).

Furthermore, if there is a two-way direction cycling lane for cyclists this can cause a higher risk of crashes between cyclists and motorized vehicles (van Haeften, 2010). This is mainly caused by the fact that drivers of motorized vehicles do not see the cyclists. This higher risk mainly holds for cyclists that drive in the opposite direction of motorised vehicles (van Haeften, 2010). The risk of crashes at two-way cycling lanes is around 1.5 times as high as at one-way cycling lanes (Reurings, Vlakveld, Twisk, Dijkstra, & Wijnen, 2012).

3.3.2. Human factors

Furthermore, the characteristics of the cyclist can also have an impact on traffic safety. Research was done in Palo Alto (US) on cyclist characteristics that influence the number of crashes at intersections (Wachtel & Lewiston, 1994). According to this research, cyclists that are 18 years and older have 1.8 times higher risks of collisions with motorised vehicles than children. Furthermore, they concluded that the gender of the cyclist did not influence the risk of conflicts (Wachtel & Lewiston, 1994). However, it should be considered that this research is done in the United States where the situation at intersections can be different than in the Netherlands.

Besides, the waiting times at signalised intersections can also influence the behaviour of cyclists. A study that was done in Melbourne distinct three types of behaviour to categorise red-light violators (Johnson, Charlton, & Oxley, 2008):

1. **Racers:** cyclists that approach an intersection with an amber light and accelerate but entered the intersection on a red-light signal
2. **Impatient:** cyclists that stop and wait for a red light, but still ride through the red light when they must wait too long (between 2 and 60 seconds)
3. **Runners:** ride through the red light without stopping

The type of red-light violation impacts the risk of a collision; in general, the ‘runners’ have the highest risk of a collision (Johnson, Charlton, & Oxley, 2008). In the study done in Melbourne, it was found that males were more likely to ignore red lights than females. Furthermore, most males that violated the red lights were ‘runners’ (Johnson, Charlton, & Oxley, 2008).

These days also a lot of people use mobile phones which also influence human behaviour in traffic. It is shown in the literature that the PET time of road users that are distracted by mobile phones is significantly shorter than those that are not distracted by mobile phones on roundabouts. This means that the probability to be involved in a crash will be higher for road users that are distracted by mobile phones (Haque, Oviedo-Trespalacios, Debnath, & Washington, 2016).

Furthermore, exhaustion is another often occurring human cause of crashes. It is estimated that 15-20% of crashes in the Netherlands happen because of tiredness (SWOV, 2019). However, in this research, the focus is not on human factors such as exhaustion, since information on tiredness is not observable from the video footage provided by SWOV.

3.3.3. Vehicle speed

According to the literature, vehicle speed and speed differences also have an impact on the probability that a crash will happen and how severe the crash will be (SWOV, 2021). If people drive at a higher speed, the impact of a collision will become bigger (Aarts & van Schagen, 2005). According to research done by SWOV, a 10% rise in average speed will result in a 20% increase in the number of crashes with low severity, the number of highly severe crashes will increase by 30% and the number of deadly crashes will increase with 40% (SWOV, 2021). The impact of speed changes can be calculated with Equation 3.3 (Elvik, 2013).

$$\frac{[Amount\ of\ accidents]_{after}}{[Amount\ of\ accidents]_{before}} = \left(\frac{[Speed]_{after}}{[Speed]_{before}}\right)^{x} \qquad \text{Equation 3.3}$$

Where x depends on the severity of a crash within the urban area. If the crash causes an average injury a x value of 2 can be used (SWOV, 2021). If the consequence of the crash causes severe injuries a value of 3 can be used and for a fatal crash a value of 4 can be used (SWOV, 2021).

The impact of a collision between two vehicles also depends on the type of road users involved in the crash (SWOV, 2021). For instance, pedestrians are quite vulnerable when a crash happens. In Figure 9, the probability of fatal crashes at different car speeds is shown for pedestrians of different ages.

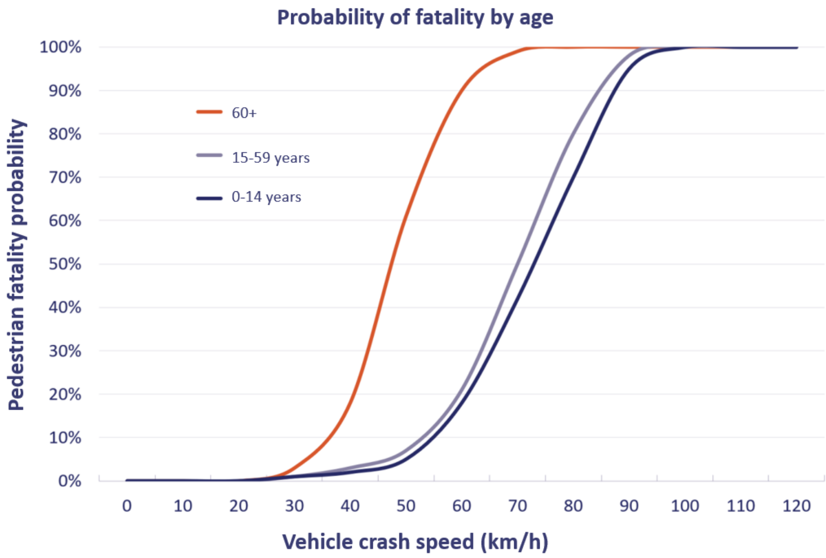

Figure 9 - Relationship between collision speed and the fatality probability of pedestrians in different age groups if they collide with a car (SWOV, 2021) (Davis in (Rosén, Stigson, & Sander, 2010))

Furthermore, the probability that a crash will happen also depends on the speed differences between vehicles. If the speed difference between two vehicles is larger the probability that a crash will occur will become higher (International Transport Forum, 2018). The probability to come into a collision will become higher since the reaction distance, braking distance and therefore the total stop distance will also become bigger for vehicles with a higher speed (see Figure 10).

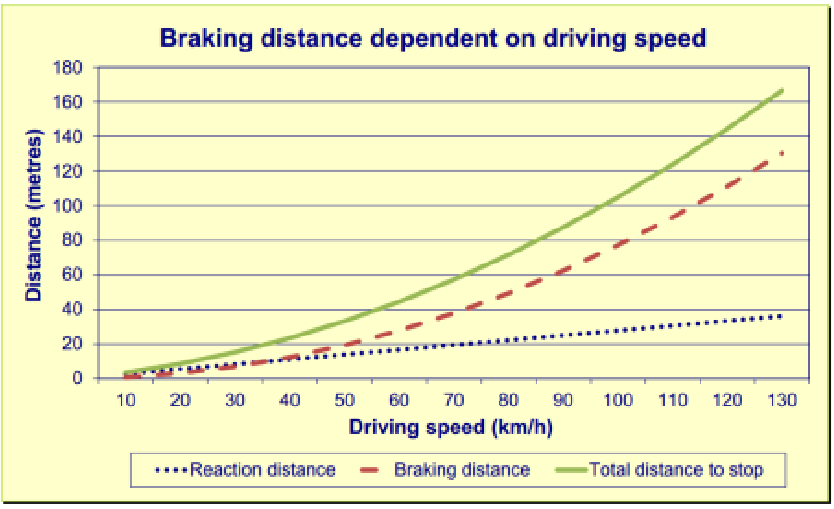

Figure 10 - Impact driving speed on braking distance (SWOV, 2012)

Besides, it is mentioned in research that people have the general tendency to overestimate lower speeds and underestimate higher speeds. As a result, it is expected that cross-decisions will become riskier as the speed of approaching major traffic increases (Spek, Wieringa, & Janssen, 2005).

3.3.4. Environment

The environment can also have an impact on safety at intersections. In research, it is found that traffic volume (the number of vehicles passing through a road over a certain period) has an impact on the amount of conflict and hence crashes at intersections (Salman & Al-Maita, 1995). However, the exact relation between traffic volume and crash frequency at intersections is not agreed on by researchers (Retallack & Ostendorf, 2020). Some researchers mention a non-linear quadratic relation between the traffic volume and crash frequency (Retallack & Ostendorf, 2020) and other papers find a linear relationship between the traffic volume and crash frequency (Cadar, Boitor, & Dumitrescu, 2017). In addition, some papers say that traffic volumes can be used to determine the severity of conflicts while other papers do not find a clear relationship between the traffic volume and the severity of conflicts (Retallack & Ostendorf, 2020). One of the papers that finds a relation between the traffic flow and the severity of crashes mentions that the higher the crash severity is the lower the subsequent traffic flow is (Mussone, Bassani, & Masci, 2017).

Furthermore, the time of day has an impact on the traffic volume and the number of crashes happening due to a lack of visibility during nighttime. According to the literature, the night-to-day crash ratio can be reduced by 30% by installing roadway lighting at intersections (Bullough, Donnell, & Rea, 2012). However, other studies find a lower percentage of 13% reduction in crashes at intersections by installing lights (Bullough, Donnell, & Rea, 2012). The night-to-day ratio is the ratio between the nighttime crash risk and the daytime crash risk.

Besides, the weather also influences the severity of crashes at intersections. For instance, sun glare can affect rear-end and angle crashes at intersections (Mitra, 2014). Also, rainfall, fog and snow can impact safety at intersections, since it affects visibility at the intersections or degrades pavement friction (Mitra, 2014).

3.4. THEORETICAL FRAMEWORK

Based on the information obtained from the literature in Paragraphs 3.1, 3.2 and 3.3, a theoretical framework is made (see Figure 11). The theoretical framework shows that there are different types of factors that influence traffic safety at intersections (as explained in Paragraph 3.3). The factors that can influence traffic safety according to the literature study in Paragraph 3.3 are; environmental characteristics, traffic intensity, vehicle speed, intersection design and human factors. However, in this study, only the influence of environmental characteristics, traffic intensity and vehicle speed on traffic safety at intersections are investigated. It is not possible to investigate the influence of intersection design on safety at intersections since only useful video footage is available for one intersection (see Paragraph 2.3). Therefore, it is not possible to compare the influence of different intersection designs on traffic safety at signalised intersections. Furthermore, it is not possible to investigate the influence of human factors such as exhaustion on the severity of conflicts since information such as exhaustion is not obtainable from the video footage.

Besides, as mentioned in Paragraph 3.1, a relationship can be found between conflicts and crashes in literature. Therefore, conflicts are suitable according to literature to investigate traffic safety at intersections (see Paragraph 3.1). In most studies that investigate traffic safety at intersections, conflict data is used since more conflict data is available than crash data. Another advantage of conflict data is that it can be obtained during a shorter period. Given all the advantages of using conflict data, it is chosen to focus on conflict data rather than crash data in this bachelor thesis.

Lastly, according to the literature study done in Paragraph 3.2, several methods can be used to measure the severity of conflicts. Five of the most mentioned measuring techniques for the severity level of conflicts in literature are; the Post Encroachment Time, the Dutch Traffic Conflict Technique, the Time-To-Collision, the Swedish Traffic Conflict Technique and the Conflict index (see Paragraph 3.2). In this study, mainly the Post Encroachment Time and the Dutch Traffic Technique are used. It is chosen to focus on the Post Encroachment time (PET) and not the Time-To-Collsion (TTC) since the PET method is more suitable to use for angle conflicts than the TTC, which is the type of conflict studied in this bachelor thesis. Furthermore, as mentioned in Paragraph 3.2, some researchers argue that the PET value on its own does not fully indicate the severity of conflicts. Therefore, the Dutch Traffic Conflict Technique is also used to investigate the severity level of conflicts since according to researchers this method gives a better indication of the severity of conflicts and the information needed for this technique is obtainable from the video footage which is not the case for techniques such as the Conflict Index. To calculate the Conflict Index the mass of the conflicting vehicles is needed, however, this information is not known. Therefore, the Conflict Index is not used in this study.

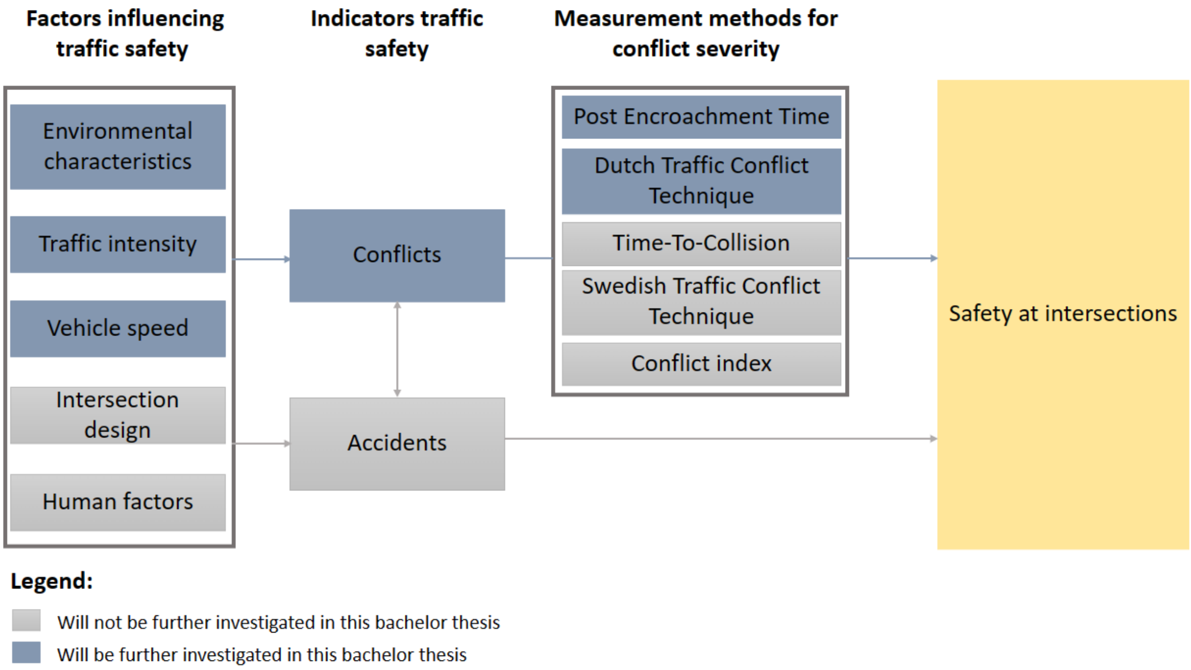

Figure 11 - Theoretical framework

4. METHODOLOGY

In this section, it is discussed which methods are used to answer the research questions described in Paragraph 1.4. As discussed in the literature review (see Paragraph 3.2) there is not one unanimous description of the relationship between the TTC / PET measurements and the severity of conflicts. To find out if there is a relationship between the PET / TTC and the severity of conflicts at intersections in the Netherlands, the video footage made by SWOV is analysed (see Chapter 2). In the video footage, only angle conflicts are observed for which only the PET is measured. The TTC is not measured for these conflicts of interest. Therefore, the relation between the TTC and the severity of conflicts is not further evaluated in this report. In Paragraph 4.1, it is described what method is used to gather data from the video footage and what method is used to analyse this data to answer the first subquestion "How can the severity of conflicts at signalised intersections be classified by using TTC or PET?".

Furthermore, several factors impact the severity of conflicts at intersections (see Paragraph 3.3). To further investigate which factors influence the severity of conflicts at signalised intersections, video data obtained by SWOV is analysed to find out if the factors found in the literature also influence the severity of conflicts between cyclists and motorized vehicles in reality at a signalised intersection in the Netherlands. In Paragraph 4.2, it is described what method is used to gather data from the video footage and what method is used to analyse this data to answer the second subquestion "What factors influence the severity of conflicts at signalised intersections?".

4.1. ANALYSING HOW THE PET CAN BE USED TO DETERMINE THE SEVERITY OF CONFLICTS BASED ON VIDEO FOOTAGE

To find out how PET value can be used to determine the severity level of conflicts at signalised intersections between motorized vehicles and cyclists, video footage is used. While watching the video footage a severity level is assigned to each conflict. Besides, it is watched whether traffic rules are broken that cause the conflict to happen and if this affects the severity level and the PET value associated with the conflict. It is assumed that if everyone would follow the rules, motorized vehicles and cyclists will probably not come into conflict with each other.

To determine how the PET/TTC values can be used to determine the severity level of conflicts the following steps are taken:

1. Make a classification for the severity levels of conflicts
2. Obtain the data
3. Analyse the data

Step 1: Classification severity level of conflicts

First of all, video footage is watched to find out to which extent the PET measurement represents the severity of conflicts. According to some researchers, the PET value does not fully indicate the severity of a conflict (see Paragraph 3.2). Therefore, it is chosen to watch video footage of multiple conflicts and to subjectively assign a severity level to these conflicts. This idea is inspired by the Dutch Traffic Conflict Technique as discussed in Paragraph 3.2.1. The ranking of severity levels used in the Dutch Traffic Conflict Technique is ranging between 1 (least severe conflict) to 5 (collision). After assigning a partly subjective severity level to each conflict, it can be investigated if these severity levels are related to the PET measurement of a conflict.

In this case, the classification of conflicts as proposed by Hydén is used to rank the severity levels of the conflicts; 'serious conflicts', 'slight conflicts', 'potential conflicts' and 'undisturbed conflicts' (Hydén, 1987) (see Paragraph 3.2.1). Such as in the Dutch Traffic Conflict Technique the severity level assigned to the conflicts is determined based on the risk of a collision and the potential seriousness of the collision if the collision would have taken place. However, it should be noted that assigning these levels is quite subjective. Therefore, a guideline is made to show which criteria are considered while determining the severity level of the conflict (see Table 2). This guideline consists of 2 aspects such as in the Dutch Traffic Conflict Technique: the possibility that the conflict will develop a collision and the severity of potential conflict consequences.

Table 2 – The severity levels of conflict (where 1 is an undisturbed conflict which indicates a safe situation, 2 is a potential conflict which indicates a potentially slightly dangerous situation, 3 is a slight conflict which indicates a slightly dangerous situation, and 4 is a serious conflict which indicates an extremely dangerous situation)

	Probability			
		High	Medium	Low
Consequences	Large	4	3	2
	Fairly Large	3	2	1
	Small	2	1	1
	Very small	1	1	1

The possibility that the conflict will develop a collision

The possibility that the conflict will develop into a collision is determined based on the actions the drivers have to take to avoid a collision instead of using the PET value such as in the Dutch Traffic Conflict Technique. It is chosen not to use the PET value since the goal is to investigate how well the PET value indicates the severity of a conflict. To investigate this, comparison material is needed that does not include the PET as part of the severity indicator of the conflict. Therefore, it is chosen to determine the possibility that a conflict will develop a conflict based on the actions the drivers of the vehicles have to take to avoid a collision. In Figure 12, it is shown what the possibility is that a conflict will develop into a collision (low, medium, high) given the action taken by the drivers. This way of determining the possibilities is inspired by research done on safety on cycling roads (Godefrooij & Hulshof, 2017). In that research, video footage is used to determine traffic safety on cycling roads with a 5-points scale based on the actions the drivers of the vehicles take. However, it should be mentioned that this way of determining the probability that a conflict will develop into a collision is quite subjective.

In this research, the probability that a conflict will develop a collision is categorised as; high, medium or low (see Figure 12). If the cyclist and motorized vehicle have to take major actions such as heavy braking, the probability of a conflict is considered to be 'high'. If the drivers only have to take a small action to avoid a collision, such as a little swerve or releasing the throttle, the likelihood of the conflict developing a collision is considered to be 'medium'. When the driver does not have to take major actions such as swerving or braking, the probability of a conflict becoming a collision is considered to be 'low'.

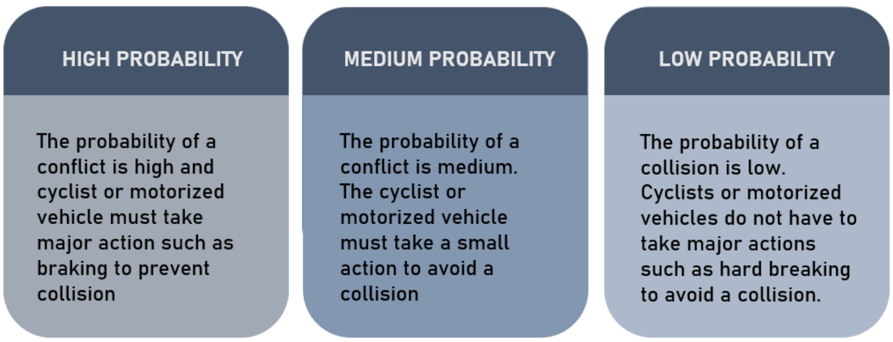

Figure 12 - The probability that a conflict will develop a collision

The severity of potential conflict consequences

The severity of potential conflict consequences is mainly determined by the speed at which motorized vehicles are driving (see literature review in Paragraph 3.2.2). Furthermore, the consequences of a collision between two vehicles are based on the type of conflict and the type of vehicles involved in the conflict. To determine the potential consequences of a conflict information about the kinetic energy can be used according to research done by Alhajyaseen as discussed in Paragraph 3.2.2 (Alhajyaseen, 2014). However, the mass of the vehicles observed in the videos is not known which makes it impossible to determine the kinetic energy exactly for every motorized vehicle. Therefore, the severity of potential conflict consequences is determined based on only the speed that the motorized vehicles drive.

If a car drives at a higher speed than 30 km/h, a crash can become fatal as discussed in the literature review (see Figure 8 in paragraph 3.2.2.). Therefore, for conflicts in which motorized vehicles drive faster than 30 km/h, the consequences of conflicts are categorized as 'large consequences'. If the speed of the vehicles is between 20 and 30 km/h, the probability of a fatal crash is low, but the probability of large injuries is still considerably large, hence these types of conflicts fall in the category of 'fairly large consequences'. If the speed of the vehicle becomes lower (between 10 and 20 km/h) the consequences of a collision are smaller, therefore conflicts with this speed range are categorized as 'small consequences'. The last category is 'very small consequences'. In this category the speed is below 10 km/h and the consequences of a collision are very small. It should be mentioned that the age of the cyclist involved in the crash can also impact the consequences of a conflict (see Figure 9, Paragraph 3.3). However, the age of the cyclist cannot be determined from the video footage and is therefore not considered in this categorisation. In Figure 13, a summary of potential conflict consequences categories is shown.

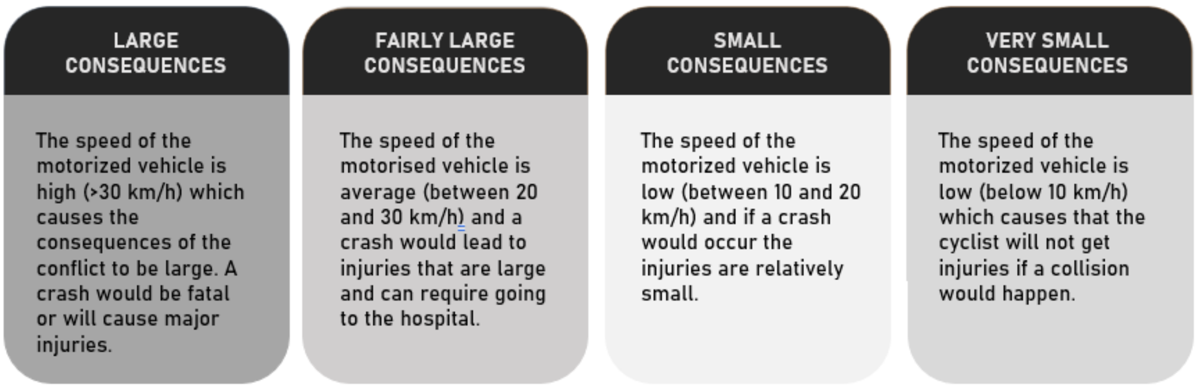

Figure 13 - Categorisation of potential conflict consequences

Step 2: Data collection

Video footage is watched to obtain information on the probability that a conflict will develop into a collision. Due to the 10 weeks time limit for this project, it is chosen to only look for a week time at video footage of conflicts at the Calandstraat for six different interaction types between cyclists and motorized vehicles that are clearly visible in the video footage and where a lot of conflicts happen. It is chosen to not look at the intersection between the Eerste Tochtweg and the Zuidelijke Dwarsweg in Nieuwerkerk aan den Ijssel since the data available for this intersection is limited (see Paragraph 2.3). Only 29 interactions are recorded at this intersection with a PET below 2 seconds. Furthermore, it is chosen to not focus on the intersection between the Mauritskade and Denneweg in The Hague, since at the Mauritskade a lot of situations are identified by the software to be a conflict while in reality it is not a conflict. It is observed in the video footage that this is mainly caused by the fact that the cycling lane is not separated from the main road for motorized vehicles which causes the software sometimes to recognise a cyclist that is passing a motorized vehicle as a conflict.

As can be seen in Figure 14, there is a lot of annual traffic daily at the intersection between the Calandstraat and the Waldorpstraat, especially towards the northern part. Therefore, it is chosen to look at 6 different conflict scenarios in which the motorized vehicles drive towards the northern direction:

- Eastbound through bike (yellow 1 in Figure 14) – Eastbound left turn motorized vehicle (yellow 5 in Figure 14)
- Eastbound through bike (yellow 1 in Figure 14) – Northbound through motorized vehicle (yellow 4 in Figure 14)
- Eastbound through bike (yellow 1 in Figure 14) – Westbound right turn motorized vehicle (yellow 3 in Figure 14)
- Westbound through bike (yellow 2 in Figure 14) – Eastbound left turn motorized vehicle (yellow 5 in Figure 14)
- Westbound through bike (yellow 2 in Figure 14) – Northbound through motorized vehicle (yellow 4 in Figure 14)
- Westbound through bike (yellow 2 in Figure 14) – Westbound right turn motorized vehicle (yellow 3 in Figure 14)

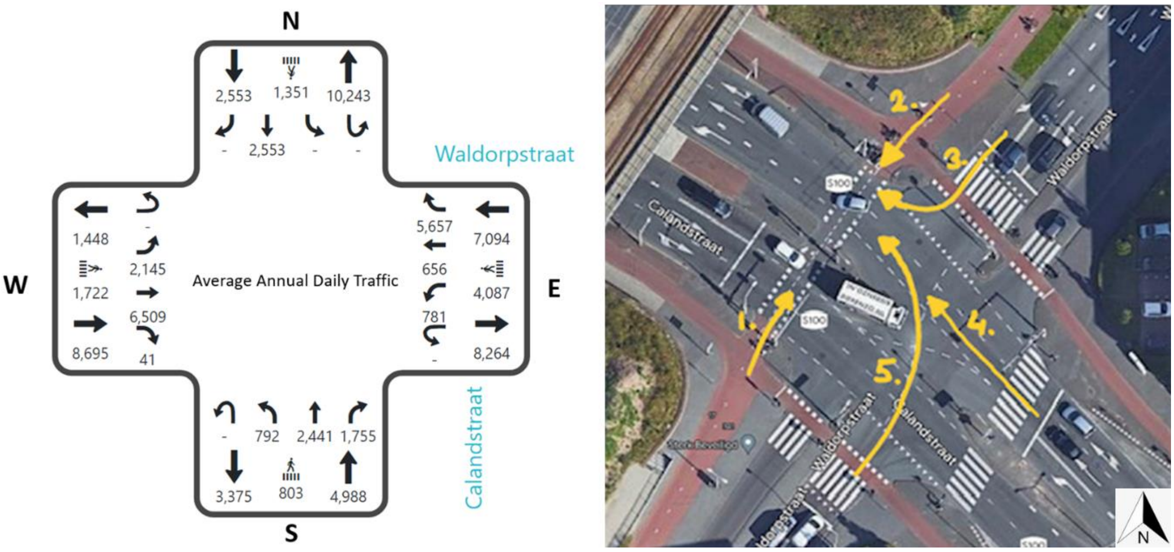

Figure 14 - Intersection Waldorpstraat & Calandstraat average annual daily traffic (left figure) and intersection Waldorpstraat & Calandstraat traffic directions (right figure)

Video footage is available for all conflicts with a PET below 2.0 seconds. It is chosen for all the scenarios to watch all the conflicts below 1.0 seconds PET. However, for the scenarios 'Eastbound through bike – Westbound right turn motorized vehicle' and 'Westbound through bike – Westbound right turn motorized vehicle', a lot of conflicts happen between 1.0 and 2.0 seconds PET. Therefore, it is chosen for these two scenarios to make a random selection of at least 40 conflicts that are watched between 1.0 and 2.0 seconds PET due to time limitations. For the other four scenarios, all conflicts are watched between 0.0 and 2.0 seconds PET. In Table 3, an overview is given of how many conflicts are watched for every scenario. In total 302 conflicts are watched in a week, which means that each day 60 conflicts needed to be watched which was feasible. It should be noted that all these limitations mentioned above can cause less accurate results. For instance, in the video footage, only 2 conflicts are found with a PET value below 1.0 seconds for the scenario 'Westbound through bike – Northbound through motorized vehicle', which makes it difficult to draw conclusions based on only this information.

Table 3 - Number of conflict videos that are watched of the intersection between the Calandstraat and the Waldorpstraat

Scenario	Number of observations $PET < 1.0$	Number of observations $1.0 \leq PET < 2.0$
Eastbound through bike – Eastbound left turn motorized vehicle	9	18
Eastbound through bike – Northbound through motorized vehicle	13	44
Eastbound through bike – Westbound right turn motorized vehicle	46	62
Westbound through bike – Eastbound left turn motorized vehicle	2	7
Westbound through bike – Northbound through motorized vehicle	2	25
Westbound through bike – Westbound right turn motorized vehicle	31	43

Step 3: Analysis methods

Statistics are used, such as the minimum, maximum and average severity levels for different PET thresholds, to analyse the relationship between the PET values and the subjectively assigned severity levels to the conflicts. Furthermore, while watching the video footage it is noted down if certain situations are seen that influence the severity of the conflict and the PET.

Besides, a one-way ANOVA (Analysis of Variance) test is used to test if there is a significant difference among certain group means (e.g. the mean speed of the motorized vehicles for different severity levels, where the severity level represents a group). The null hypothesis is that there is no difference among the group means (Kim Kyun, 2016). The alternative hypothesis is that at least one group mean differs significantly from the other groups. If the p-value is lower than 0.05 (Gonzalez-Chica, Duquia, Martinez-Mesa, Bastos, & Bonamigo, 2015) it can be concluded that there is a significant mean difference between the two groups.

Furthermore, crash data collected between 2010 and 2020 by the police and Rijkswaterstaat at the intersection of the Calandstraat with the Waldorpstraat in The Hague is used to determine if a relationship can be found between the severity of crashes and the severity level of the conflicts recorded from the video footage. However, crash data is sensitive information, therefore, only information is available on whether the crash was fatal, resulted in injury or resulted only in material damage. There is no data available on how serious the injuries are since this is sensitive information. So, it is assumed that if a crash is fatal this corresponds with the highest severity level (severity level 4). If the crash led to injuries, it is assumed that this corresponds with a medium severity level (severity level 3) and if the crash only resulted in material damage the severity level is low (severity level 2) (see Step 1, Paragraph 4.1). Lastly, it should be noted that small incidents are often underreported (SWOV, 2016).

4.2. Analysing what factors influence the severity of conflicts at signalised intersections

To analyse which factors influence the severity of conflicts, the video footage made by SWOV is watched (see Chapter 2). Based on the data derived from the video footage a model is made that predicts the severity level of a conflict based on different factors obtained from the video footage. Subsequently, it is discussed if the observations from the video data are in line with the findings of the literature review (see Chapter 3.3).

To find the factors that influence the number of conflicts the following steps are made:

1. Make a list of factors that can influence the severity of conflicts at signalised intersections between cyclists and motorized vehicles and which can be obtained from the video footage.
2. Obtain the data
3. Analyse the data

Step 1: Factors that influence the severity of conflicts at signalised intersections
As discussed in the literature review, several factors influence traffic safety at signalised intersections (see Paragraph 3.3). However, not all these factors are well obtainable in the video footage obtained by SWOV. For instance, it is not possible to obtain the gender of the cyclist and the driver of the motorized vehicle in the video footage, due to the view angle of the camera. Furthermore, during the days that video footage was obtained the weather was good and it did not rain, which makes it impossible to use this data to examine the impact of weather on the severity of conflicts. Furthermore, the impact of intersection design on the severity level of conflicts can also not be investigated with the available data, since only data is used from one intersection. Therefore, only the best measurable factors are obtained from the video footage. The factors that are obtained from the video footage for each conflict are:

- **Vehicle speed:** as discussed in the literature review (see Paragraph 3.3) the higher the speed (differences) of vehicles the more severe the consequences of a crash and hence the more severe the conflict will be. The speed of the vehicles is given by the software TrafxSAFE in miles per hour.
- **Traffic intensity:** as discussed in the literature review (see Paragraph 3.3), if the traffic intensity is higher the number of crashes will also become higher. However, there is no consensus among researchers about the exact relationship between traffic intensity and the severity of conflicts. The traffic intensity is given by the software TrafxSAFE in average hourly traffic volume.
- **The time of day:** the time of day is shown by TransxSAFE for every conflict, the time of day can be used to make a separation between peak hours with a high traffic intensity and non-peak hours with a lower traffic intensity.
- **Light intensity:** according to research (see Paragraph 3.3) light intensity also impacts the number of crashes. The better the lighting at an intersection the fewer crashes will happen. The lighting intensity is categorised into four levels: daylight, twilight, dark, and dark but with streetlights that are turned on.
- **Cycling in groups:** in the literature, nothing is found about the influence of cycling in big groups on the severity of conflicts. However, it is interesting to investigate if cycling in groups influences the severity of conflicts. Therefore, it is noted down if the cyclist drives alone, in a duo or in a big group.
- **Type of cyclist:** in the literature review nothing can be found about the type of bicycle on the severity of crashes. To find out if the type of bicycle also impacts the probability of a crash it is

noted down if the bicycle has a crate on the front of the bicycle, is a standard bicycle, a cargo bike or a moped.

- **Traffic offences:** it is noted down if one of the conflicting vehicles breaks the traffic rules and which type of rule is broken. The types of traffic offences considered are; red traffic light violation, driving through ample light, driving in the wrong lane, and other types of traffic offences or no traffic offence observed.
- **Who breaks the rules:** furthermore, it is written down who breaks the rules in case of a traffic offence (the cyclist of the motorized vehicle). This will be done to investigate if there is a relation between who breaks the traffic rules and the severity level of conflicts.
- **Who goes first:** it is also written down if the cyclist first enters the conflict point or if the motorized vehicle first enters the conflict point.
- **Specialities:** if remarkable things are seen while watching the video data this is also written down.

Step 2: Data collection

The factors that possibly influence the severity of the conflicts are collected for the same interactions as mentioned in Paragraph 4.1, step 2. As already discussed in Paragraph 2.3, the information that can be obtained from the video footage is limited due to two reasons;

1. Video footage is made in only one week (see Chapter 2.3). During the week they filmed the video the weather was for instance good. Therefore, the impact of the weather on the severity of conflicts at intersections cannot be found based on this data. Furthermore, only three intersections are filmed which makes it impossible to compare the impact of different intersection designs on the severity level of conflicts. Especially since for not all the intersections a lot of conflicts are observed.
2. Obtaining different factors manually from the video footage takes a lot of time. However, the time for this research is limited, therefore it is chosen to only watch video footage for a week which can influence the results (see Paragraph 4.1, step 2).

Step 3: Analysis method

Two different methods are used to investigate which factors influence the severity of conflicts at signalised intersections. The two analysis methods that are used are; descriptive statistics and a multinomial logistic regression model.

Descriptive statistics

First of all, to find a relationship between certain factors and the severity of conflicts descriptive statistics are used, such as the mean. Furthermore, the collected data is visualised with graphs such as histograms and scatter plots. By using descriptive statistics insight can be created into which factors influence the severity of conflicts. To get a more detailed insight into how certain factors, such as the type of cyclist, influence the severity of conflicts a multinomial logistic regression model is made.

Multinomial logistic regression model

A multinomial logistic regression model is made in the statistical software SPSS to predict the severity level of a conflict based on different factors. A multinomial logistic regression model is a model that predicts a nominal dependent variable based on one or more independent variables. In this research, the dependent variable is the severity level of a conflict. The independent variables are the different factors obtained by watching video data. An alternative model to predict the severity level of a conflict is an ordinal regression model. However, it is chosen to use a multinomial logistic regression model since this type of model is used in multiple pieces of research about factors that influence the severity of crashes and gave useful results (Shiran, Imaninasab, & Khayamim, 2021) (Kim, Kim, Ulfarsson, &

Porrello, 2007). Furthermore, a logistic regression model gives a good insight into how the different independent variables influence the severity levels compared to each other.

Formula multinomial logistic regression model

In a multinomial regression model, the function as shown in Equation 4.1 is used (Abdalla, 2012). In this formula logits are constructed by using a base level category, every of the k categories of the dependent variable can be this base level.

$$\log\left[\frac{\pi_j(x_i)}{\pi_k(x_i)}\right] = \alpha_{0i} + \beta_{1j}x_{1i} + \beta_{j2}x_{2i} + \cdots + \beta_{pj}x_{pi} \qquad \text{Equation 4.1}$$

Where j = 1,2,….,(k-1) and i = 1,2,…,n. Equation 4.1 can be rewritten as the formulas shown in Equation 4.2 (Abdalla, 2012).

$$\log\left(\pi_j(x_i)\right) = \frac{exp(\alpha_{0i}+\beta_{1j}x_{1i} + \beta_{j2}x_{2i}+\cdots+\beta_{pj}x_{pi})}{1+\sum_{j=1}^{k-1}\exp(\alpha_{0i}+\beta_{1j}x_{1i} + \beta_{j2}x_{2i}+\cdots+\beta_{pj}x_{pi})} \qquad \text{Equation 4.2}$$

Where:

- π_j is the probability of an observation falling in the j^{th} category
- β_i refers to the effect of x_i on the logit
- p is the number of independent variables used in the model
- k is the number of categories the dependent variable consists of
- x is the explanatory variable
- $\exp(\beta_i)$ is the effect on the odds of a one-unit increase in one of the variables while the other variables stay the same

The input variables of the multinomial regression model in SPSS are the variables obtained by the software TrafxSAFE and from the video footage. The severity levels assigned to the conflicts are determined based on the answer to subquestion 1 (see Paragraph 4.1). By making this model, insight can be created into which factors are most suitable to predict the severity level of a conflict and hence influence the severity of conflicts.

Assumptions multinomial logistic regression model

To make a multinomial logistic regression model, the input data should be tested on six assumptions (Leard Statistics, n.d.):

1. The dependent variable should be measured at the nominal level.
2. There are one or more independent variables that are continuous, ordinal or nominal. However, ordinal independent variables should be treated as continuous or nominal variables.
3. The observations should be independent of each other, and the dependent variable should have mutually exclusive and exhaustive categories.
4. There should not be multicollinearity.
5. There needs to be a linear relationship between the logit transformation of the dependent variables and any continuous independent variables.
6. There should be no highly influential points or outliers.

The first three assumptions can be checked by just looking at the data set and checking if these assumptions are met. To check the fourth assumption “there should not be multicollinearity”, it should be checked if there is a correlation between the independent variables. If there is a high correlation between the independent variables only one of the two independent variables should be used in the model. Therefore, the Pearson method is used to calculate the linear correlation between different factors. The Pearson formula to calculate the correlation coefficient is given in Equation 4.3 (van Heijst, 2022).

$$r = \frac{\sum((x_i - \bar{x})\,(y_i - \bar{y}))/(N-1)}{s(x)s(y)} \qquad \text{Equation 4.3}$$

Where:

- r is the Pearson correlation coefficient
- y_i and x_i are the observations
- $\bar{x}$ and $\bar{y}$ are the sample means
- $s(x)$ and $s(y)$ are the standard deviation of the sample
- N is the size of the sample

The calculated Pearson coefficient varies between -1 and 1. If the Pearson correlation (r) is between $\mp$ 0.00 and $\mp$0.30 there is hardly any or no correlation (van Heijst, 2022). Furthermore, if the Pearson correlation is between $\mp$0.30 and $\mp$0.50 there is a low or weak correlation. In addition, if the correlation is between $\mp$0.50 and $\mp$0.70 there is a medium correlation. If the correlation is between $\mp$0.70 and $\mp$0.90 the correlation is high. Lastly, if the correlation is higher than $+0.90$ or lower than -0.90 there is a strong correlation. Therefore, it is chosen to not incorporate variables with a correlation above $+0.70$ and lower than -0.70 into the model.

The last assumption that should be checked is whether there are no highly influential points, high-leverage values or outliers. This assumption is checked while looking at the video footage of conflicts. If outliers are detected this is noted down.

Interpretation of the results coming from the multinomial logistic regression model

After building the multinomial logistic model it is checked if the model fits the data well. The goodness-of-fit is checked by looking at the model-fitting information that will be given in SPSS. If the model fits the data well, the results of the model are further evaluated. If the model does not fit the data well a new model is made.

If the model fits the data well, it is investigated which independent variables are significantly significant (95% significance level) by performing a likelihood ratio test in SPSS. If a certain independent variable is statistically significant, it can be determined based on the regression coefficient how the independent variable influence the severity level of a conflict. The model estimates for each independent variable the regression coefficient. However, these regression coefficients are measured in different units which makes it difficult to compare the regression coefficients. Therefore, standardized regression coefficients are used to eliminate this problem (Siegel & Wagner, 2022). The standardized regression coefficient can be calculated with Equation 4.4 (Siegel & Wagner, 2022).

$$Standardized\ regression\ coefficienct = b_i \frac{S_{Xi}}{S_y} \qquad \text{Equation 4.4}$$

Where:

- b_i is the regression coefficient
- S_{Xi} is the standard deviation of the independent variable
- S_y is the standard deviation of the dependent variable

Lastly, it is checked how well the built model in SPSS predicts the severity class of a conflict. This is done by comparing the predicted severity levels with the actual severity levels given in the data set. Furthermore, it is checked if the results of the model are comparable to the literature, to find out if the model works as it is supposed to and if no errors are made while making the model.

5. RESULTS

In this chapter, the results are shown to answer the first subquestion "How can the severity of conflicts at signalised intersections be classified by using TTC or PET?" (see Paragraph 5.1). Secondly, in Paragraph 5.2, the results are shown to answer the second subquestion "What factors influence the severity of conflicts at signalised intersections?".

5.1. RELATIONSHIP BETWEEN PET/TTC AND THE SEVERITY OF CONFLICTS BASED ON VIDEO FOOTAGE

While observing the 6 scenarios as mentioned in Paragraph 4.1, only angle conflicts are observed. For these types of conflicts only the PET value is available since the PET value describes better than the TTC value angle conflicts (Arun, Haque, Washington, Sayed, & Mannering, 2021). Therefore, the results are focused on the PET value.

5.1.1. General observations

First of all, it is counted for the 6 scenarios at the Calandstraat how often certain PET values are observed. In Figure 15, it is shown that up to a PET value of 7 seconds, the number of interactions between cyclists and vehicles is increasing. After this PET value of 7 seconds, the number of interactions between cyclists and motorized vehicles drops again. The shape of Figure 15 is in line with Figure 4 as discussed in the literature review (see Paragraph 3.1). Furthermore, it is observed that the more severe the conflicts are the less often they occur (see Table 4 and see Paragraph 4.1 for the severity scale), which is also in line with the literature review (see Paragraph 3.1). In Table 5, it is shown how often conflicts occur with a certain probability to develop a collision and a certain consequence level as discussed in Paragraph 4.1.

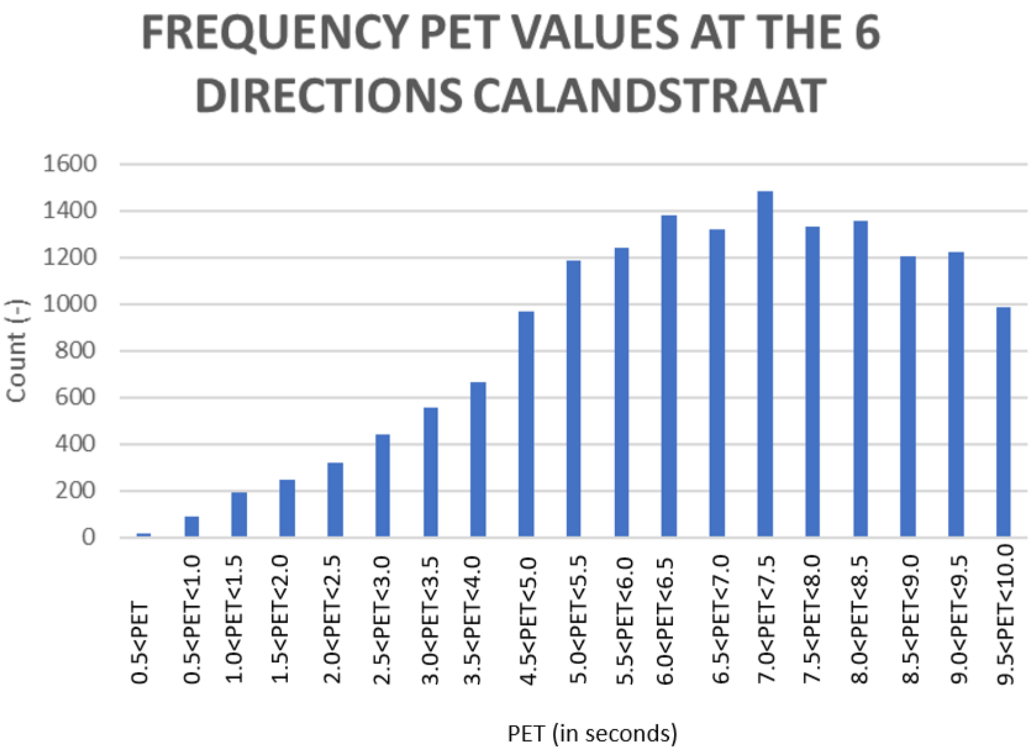

Figure 15 - Frequency PET values at the 6 directions Calandstraat

Table 4 - Number of observations for each severity level

Severity level (-)	Number of observations (-)
1	192
2	80
3	30
4	0

As can be seen in Table 5, almost no conflicts are detected with a high probability of developing a collision. This means that in the video footage, almost no situations are detected in which the vehicles have to take large actions to avoid conflicts. This indicates that the observed intersection is relatively safe, which is also in line with the fact that only 5 conflicts happened in the past ten years at this intersection with injuries as a result. In the past 10 years, also no fatal crashes have happened between cyclists and motorized vehicles at this intersection.

Table 5 - Number of conflicts with a certain probability to turn into a collision and the severity of potential conflict consequences

		Probability		
		High	Medium	Low
Consequences	Large	0	30	52
	Fairly Large	0	25	27
	Small	3	60	93
	Very small	0	7	5

5.1.2. Relation conflicts and crashes between cyclists and motorized vehicles

Secondly, as discussed in the methodology (see Paragraph 4.1), crash data of the intersection between the Calandstraat and the Waldorpstraat is used to investigate if there is a relation between crashes and conflicts. The conflicts and crashes considered in this research are crashes and conflicts between cyclists or other cycle-path users and motorized vehicles. As already mentioned in the methodology, crash data contains sensitive information and therefore only data is available on whether the crash was fatal, resulted in injury or resulted only in material damage. As discussed in the methodology (see Paragraph 4.1), fatal crashes are assumed to correspond with a severity level of 4, injuries with a severity level of 3 and material damage with a severity level of 2. In Table 6, it is shown how often crashes with a certain severity level are registered between 2010 and 2020. As can be seen, not a lot of crashes have been registered over the last 10 years for the intersection between the Calandstraat and the Waldorpstaat. Furthermore, no fatal crashes have occurred in the last 10 years at the intersection between the Calandstraat and the Waldorpstraat in the Hague. This finding is in line with the fact that no serious conflicts (conflict level 4), are detected in the video footage. The fact that no fatal crashes have occurred in the last ten years at the intersection analysed in this report means that it cannot adequately be tested if there is a relation between the number of conflicts and crashes for the highest severity level. Besides, as can be seen in Table 6, crashes with a higher severity level occur less often than crashes with a lower severity level. This shows the same pattern as found for how often conflicts with a certain severity level are observed at the intersection of the Calandstraat and the Waldorpstraat in The Hague.

Table 6 - Number of observed conflicts and crashes for different severity levels

Severity level	Number of observed conflicts (-)	Number of observed crashes (-)
2	80	15
3	30	5
4	0	0

In Figure 16, a visualisation is given for the relation between the number of severe conflicts and crashes. However, it should be mentioned that limited data has been used, which can cause uncertainties in the results. As discussed in the literature review (see Paragraph 3.1), the expected number of crashes can be calculated based on conflict data by multiplying the number of observed traffic conflicts and the crash conflict ratio (Hauer, 1982). However, since the number of crashes is recorded over a longer period than the conflicts and conflicts are only measured for a PET lower than 2.0 seconds, it is not possible with the gathered data to determine the crash-conflict ratio. Therefore, it is recommended to gather more data over a longer period for multiple intersections to find information on the crash-conflict ratio.

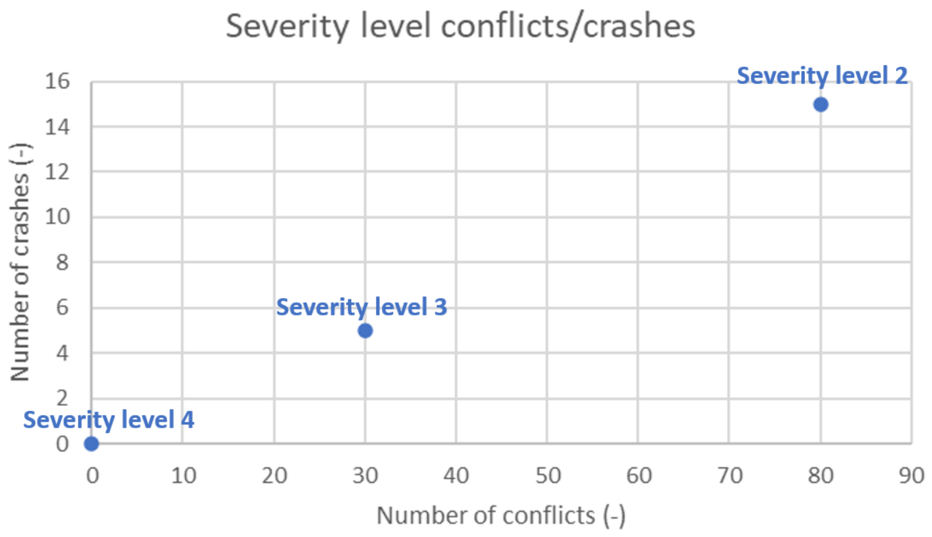

Figure 16 - Number of conflicts and crashes for different severity levels

Furthermore, it is investigated if the conflicts observed in the video footage occurred at the same time of the day as the crashes happened at the intersection between the Calandstraat and the Waldorpstraat between 2010 and 2020. This is done to investigate the relationship between conflicts and crashes. If crashes occur in the same pattern as conflicts, this can indicate a relation between crashes and conflicts. In Figure 17, it is shown how many conflicts with a severity level between 2 and 4 are observed for which time of day, in the week of video data made by SWOV. Furthermore, Figure 17 also shows how many crashes are observed over the last 10 years for which times of the day. The conflicts with a severity level of 1 are not taken into account since these types of conflicts are probably not resulting in a severe crash that is registered. Furthermore, in Figure 18, a plot is given with on the x-axis the number of crashes and on the y-axis the number of conflicts for every hour of the day. However, as shown in Figure 17 and Figure 18, no clear relation could be found between the time of day that conflicts happen and the time of day at which crashes happen based on the available data.

It should be noted that the amount of crash data is limited (20 observations), which can be the cause of the fact that no relation can be found between conflicts and crashes based on the time of day that the conflicts and crashes happened. Furthermore, it can also be the case that there is no relation between time of day and conflicts/crashes, which can also cause that no relation can be found between the number of conflicts and crashes based on the time of the day. However, it could be found that for as well crashes as conflicts it holds that between 00:00 and 08:00 the number of conflicts and crashes is low, while between 08:00 and 00:00 the number of crashes and conflicts is higher. To find out if the crashes occur in the same pattern as conflicts at intersections based on the time of day with more certainty, it is recommended to investigate intersections for which more crash data is available.

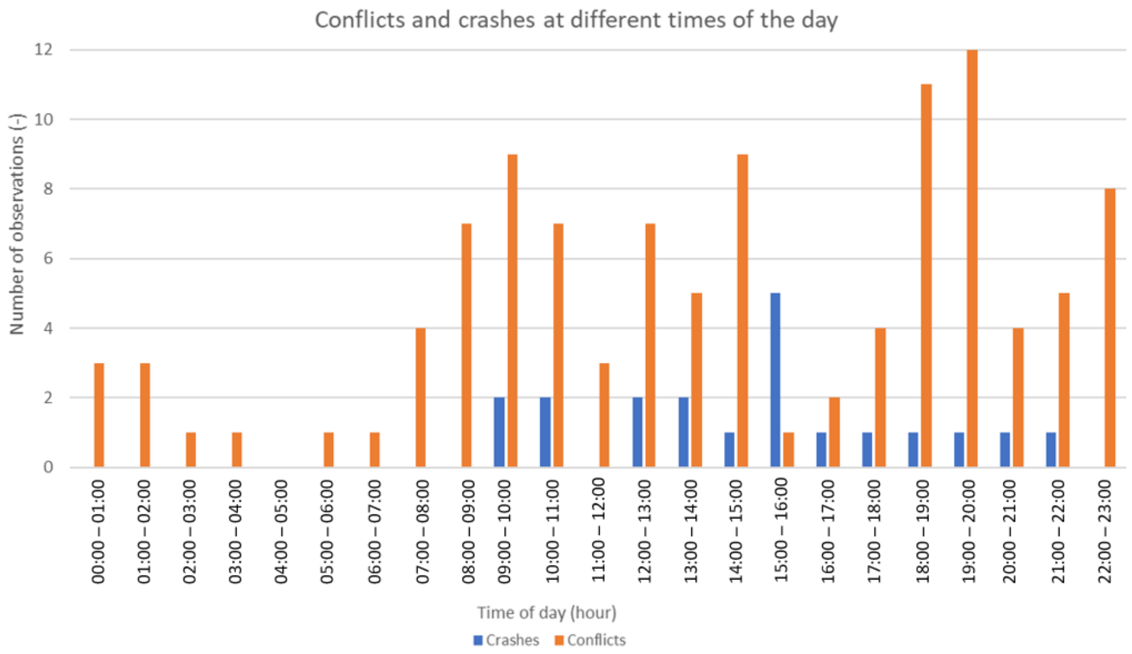

Figure 17 - Conflicts and crashes at different times of the day (conflicts observed in one week time and the crashes are observed over ten years)

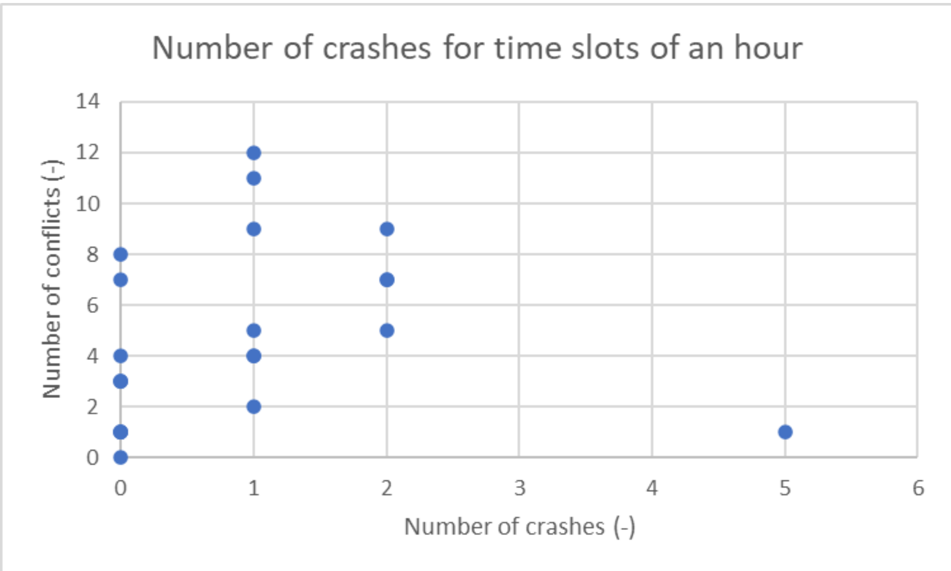

Figure 18 - Number of crashes compared to the number of crashes for time slots of an hour (conflicts are observed in one week time and the crashes are observed over ten years)

5.1.3. Severity levels for different scenarios

Thirdly, it is observed that the average severity level of conflicts is different for different scenarios. This average severity level is determined for conflicts with a PET value between 0.0 and 2.0 seconds since only these conflicts are observed in the video footage (see Paragraph 2.3). As can be seen in Table 7, interactions between cyclists and northbound through motorized vehicles have the highest average severity. This can partly be explained by the fact that the motorized vehicles coming from this direction drive at a higher speed than traffic from the other directions (see Table 7), which causes the conflicts to be more severe. The lowest average severity level is found for conflicts between cyclists and westbound right-turn motorized vehicles (see Table 7). This can be the case because most of these conflicts are caused by motorized vehicles that are driving through orange or just red signals. The cyclists are often standing still when the motorized vehicles drive through orange or just red traffic lights and only start moving just after the motorized vehicle has passed. As a result, the risk of a collision is often small because cyclists almost always see the motorized vehicle coming and only start moving once the motorized vehicle has passed. Furthermore, since the motorized vehicles in this direction make a turn of around 90 degrees, their speed is relatively low which decreases the potential consequences of the conflict (see literature review Paragraph 3.2.2, Figure 8). Therefore, this type of interaction has a low PET value while the probability of a conflict resulting in a collision is low.

Table 7 - Average severity level conflicts for different scenarios

Scenario	The average severity level (-)	Number of observations (-)	Average speed motorized vehicle (km/h)	Average speed cyclist (km/h)
Eastbound through bike - Eastbound left turn motorized vehicle	1.63	27	27.3	16.8
Eastbound through bike - Northbound through motorized vehicle	2.21	57	35.7	15.6
Eastbound through bike - Westbound right turn motorized vehicle	1.06	108	15.6	16.8
Westbound through bike - Eastbound left turn motorized vehicle	1.78	9	25.2	13.7
Westbound through bike - Northbound through motorized vehicle	2.11	27	33.5	9.2
Westbound through bike - Westbound right turn motorized vehicle	1.14	74	17.3	8.6

Besides, a one-way ANOVA (Analysis of Variance) test is used to test if there is a significant difference in mean motorized vehicle speed for different scenarios and severity levels (see the methodology in Paragraph 4.1). First of all, according to the ANOVA test, there is a significant difference in mean speed for different scenarios (see Appendix B.1). Furthermore, there is a significant difference in the mean speed for different severity levels (see Appendix B.2). In Figure 19, a scatterplot is shown which also shows that in general, the speed is higher for more severe conflicts. Besides, in Figure 19, it can also be seen that conflicts with a severity level of three occur less often if the PET is higher than 1.5 seconds. So, in general, it is observed that the higher the motorized vehicle speed is, the higher the severity of the conflicts is.

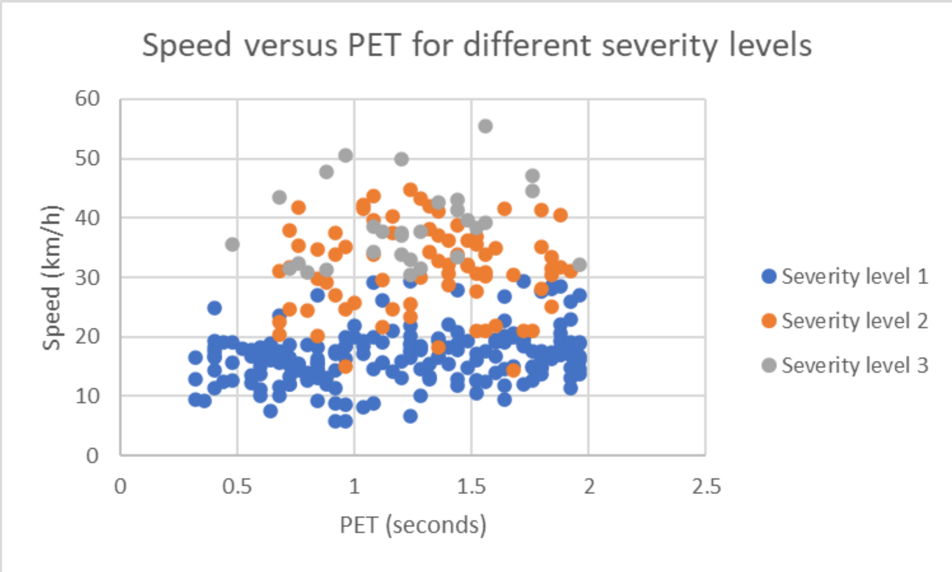

Figure 19 - Scatterplot speed versus PET for different severity levels

5.1.4. Relation between the Post Encroachment Time and severity level

Furthermore, it is observed that the PET value does not always describe straightforwardly the severity of a conflict as defined in this study. From the literature, it is expected that the lower the PET value the higher the severity of a conflict and the higher the probability that a conflict will develop a collision (see Paragraph 3.2). Based on watching the video footage this is not always the case. By doing an ANOVA test it is shown that there is not a significant difference between the mean PET values for different severity levels (see Appendix B.3), which indicates that there is no relation between the PET and the severity level of a conflict. However, it should be mentioned that only 18 situations have occurred with a PET value below 0.5 seconds, so the conclusions that can be drawn for this category are limited. As can be seen in Table 8, the average severity level of conflicts increases until a PET value of 1.5 seconds, and after that, the severity level of the conflicts becomes lower. By watching the videos, it is concluded that this can be caused due to several reasons:

1. Most of the conflicts seen in the video footage are caused by people who do not obey traffic rules. Often these people are aware that they are breaking the rules. For example, many conflicts happen between motorised vehicles and cyclists where the cyclists run a red light just after a motorised vehicle passed by. In principle, the probability is very low that such an event will lead to a crash, but it has a low PET value.
2. In general, the speed of the vehicles is the highest for a PET value between 1.0 and 1.5 seconds which increases the potential consequences of the conflict (see Table 8). This can cause the severity level to be higher for this type of conflict.

Table 8 - The average severity level for different PET thresholds

PET (seconds)	Average severity level (-)	Number of observations (-)	Average speed motorized vehicles (km/h)	Average speed cyclists (km/h)
PET<0.5	1.11	18	16.7	13.5
0.5≤PET<1.0	1.39	85	19.9	12.8
1.0≤PET<1.5	1.65	98	26.2	14.3
1.5≤PET<2.0	1.41	101	22.9	14.1

Lastly, as can be seen in Table 9, the probability that a conflict will develop into a crash decreases a lot when the PET value becomes higher than 1.5 seconds. Therefore, it can be concluded that a PET value below 1.5 seconds can indicate that the probability of a conflict developing a crash is higher. The finding that the PET value gives an indication of the probability that a conflict will develop a collision is consistent with the findings in the literature review (see Paragraph 3.2). Furthermore, it is checked with an ANOVA test that there is a significant difference in the mean PET value for the different probability categories (high, medium, low) (see Appendix B.4). This also confirms that there is a relation between the PET and the probability of a conflict developing a collision. However, it should be mentioned that the available data is limited, which makes it impossible to claim without some uncertainty that the PET value gives an indication of the probability that a conflict will develop a conflict. It is therefore recommended to do this research on a large scale to be more certain about the results.

Table 9 - The probability level that a conflict will develop a collision

PET (seconds)	High probability of conflict developing a collision (%)	Medium probability of conflict developing a collision (%)	Low probability of conflict developing a collision (%)
PET<0.5	0.00	44.44	55.55
0.5≤PET<1.0	1.18	49.41	49.41
1.0≤PET<1.5	1.02	45.92	53.06
1.5≤PET<2.0	0.99	26.73	72.28

5.2. Factors that influence the severity of conflicts

In this paragraph, the results are given that are needed to answer sub-question 2 “What factors influence the severity of conflicts at signalised intersections?”. The results are given in two parts. The first part gives the descriptive statistics for all the factors and the second part gives the results of the multinomial logistic regression model.

5.2.1. Descriptive statistics

5.2.1.1. Vehicle speed

First of all, a relationship can be seen between the speed that motorized vehicles drives during a conflict and the severity level of the conflict (see Figure 20). The higher the speed of the motorized vehicle the higher the severity level of the conflict will be. This is logical since the severity of conflicts is determined by using the speed that motorized vehicles drive (see Paragraph 4.1, Figure 13).

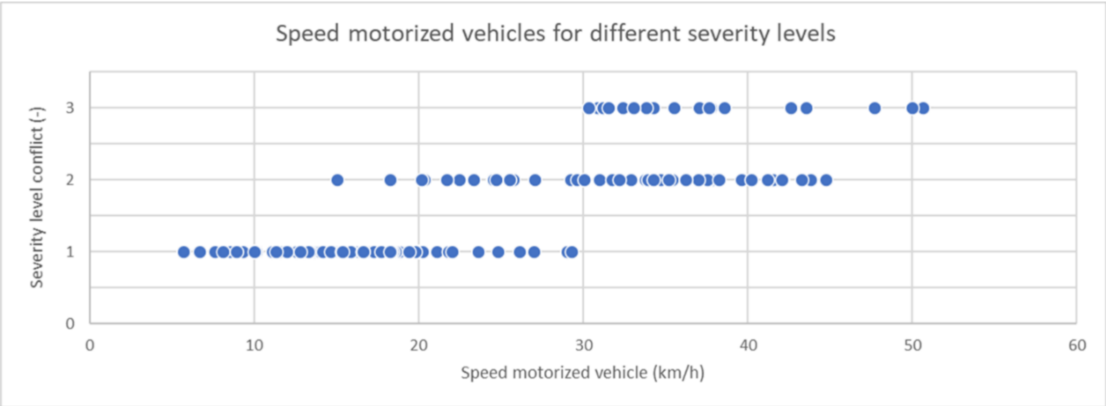

Figure 20 - Speed motorized vehicles for different severity levels

Furthermore, as shown in Table 10, the average speed of cyclists is also higher for severe crashes. However, the difference in mean for the average speed of cyclists is not statistically significant for the different severity levels (see ANOVA test in Appendix B.5). Which indicates that no relationship between the speed of cyclists and the severity level of a conflict can be found based on the available data.

Table 10 - Average speed cyclist for different severity levels

	Number of observations (-)	Average speed cyclist (km/h)
Severity level 1	192	13.51
Severity level 2	80	13.84
Severity level 3	30	15.45

5.2.1.2. Traffic intensity and peak/non-peak hours

Furthermore, as discussed in the literature review (see Paragraph 3.3), an increase in traffic intensity will result in a higher number of crashes. However, there is no consensus among researchers about the exact relationship between traffic intensity and the number of crashes (see Paragraph 3.3). Some papers say that traffic volumes can be used to determine the severity of conflicts while other papers do not find a clear relationship between the traffic volume and the severity of conflicts (Retallack & Ostendorf, 2020). To find out if there is a relation between traffic intensity and the severity of conflicts a distinction is made between peak hours (07:00-09:00 & 16:00-18:00) with a high traffic intensity and non-peak hours with a lower traffic intensity.

It is observed that during peak hours, the severity level is on average 1.52 while during non-peak hours the severity level is on average 1.44. Furthermore, as shown in Table 3, the percentage of conflicts during peak hours compared with the total number of conflicts (peak hours & non-peak hours) increases for conflicts with a higher severity level. This can indicate that traffic intensity influences the severity of conflicts. However, it should be noted that the difference in average severity level for non-peak hours and peak hours is small and can also be caused by the small number of observations.

Table 11 - Severity levels of conflicts during peak hour and non-peak hour

	Number of conflicts during peak hours (-)	Number of conflicts during non-peak hours (-)	Percentage conflicts caused during peak hours (%)
Severity level 1	47	145	24.5
Severity level 2	23	57	28.8
Severity level 3	9	21	30.0

Furthermore, in Figure 21, the traffic intensity and severity level are shown for all conflicts observed in the videos. A one-way ANOVA test is used which showed that there is a significant difference between the mean traffic intensity for different severity levels (see Appendix B.6). This can indicate a relation between the traffic intensity and the severity level of a conflict. It is found that the average traffic intensity will become higher when the severity level becomes lower (see Table 12).

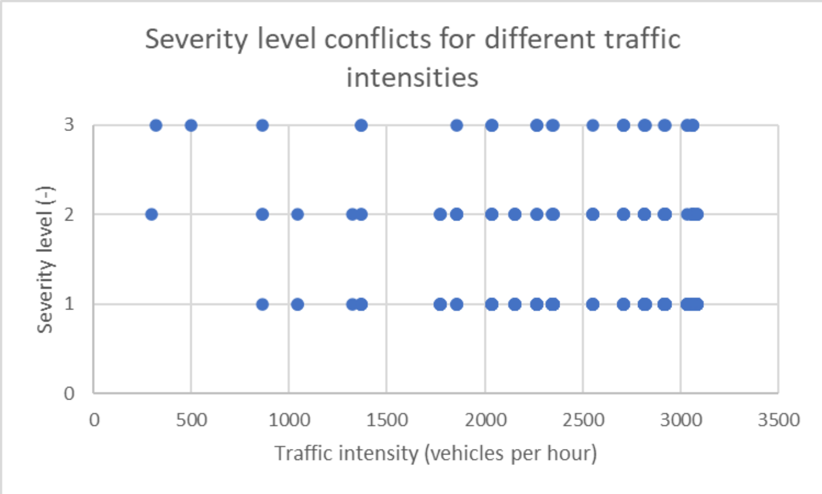

Figure 21 - Severity level conflicts for different traffic intensities

Table 12 - Average traffic intensity for different severity levels

	Number of observations (-)	Average traffic intensity (vehicles/hour)
Severity level 1	192	2569
Severity level 2	80	2434
Severity level 3	30	2330

The fact that when the average traffic intensity is lower the average severity level of the conflict will be higher, can be caused by the fact that when the traffic intensity is higher the speed of the vehicles is in general lower (see Figure 22). If the speed of the motorized vehicle is lower this also reduces the severity of a conflict (see literature review Paragraph 3.2.2, Figure 8). However, the correlation coefficient calculated with Pearson between the speed of the motorized vehicle and the traffic intensity is -0.22, which indicates hardly a correlation (van Heijst, 2022).

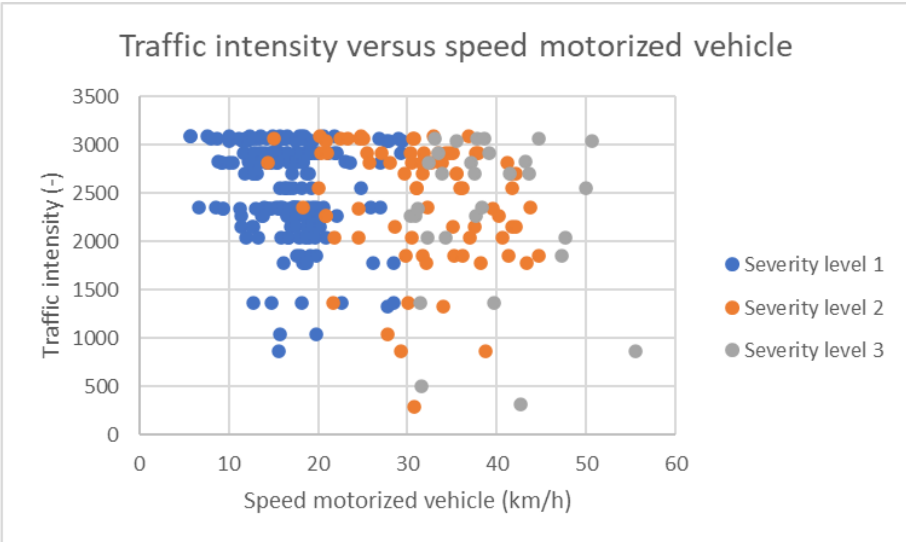

Figure 22 - Traffic intensity versus speed motorized vehicle

5.2.1.3. Light intensity

Another factor that can influence the number of severe crashes according to the literature is visibility (see Paragraph 3.3). Therefore, while watching the video footage is noted down if there was daylight (high visibility), twilight (lower visibility) or if it was dark outside (lowest visibility). However, it should be noted that when it became dark the streetlights were turned on. In Figure 23 & Table 13, it can be seen that the average severity of conflicts is higher when it is dark than when it is light outside. This can be caused by the visibility of cyclists and motorized vehicles, but it can also be caused by the fact that the traffic intensity is low when it is dark outside. The correlation calculated with Pearson between traffic intensity and light intensity is -0.63, which indicates a medium correlation (van Heijst, 2022).

Furthermore, the number of conflicts observed when it was dark outside is limited (14 observations), since the video footage is made within the summer period in which it is only day dark outside for a few hours a day. Therefore, it is not possible to draw conclusions on the relation between the light intensity and the severity of conflicts between cyclists and motorized vehicles with high certainty.

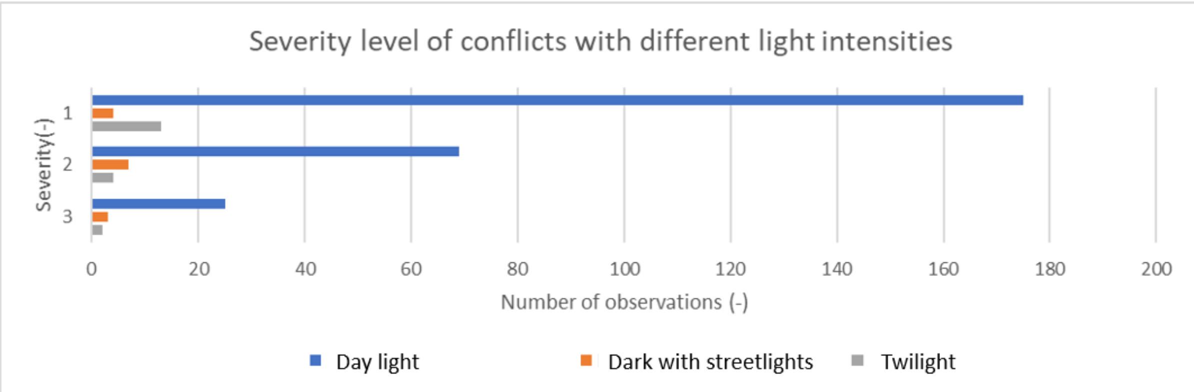

Figure 23 - Severity level of conflicts with different light intensities

Table 13 – Average severity level and number of observations for conflicts with different light intensities

Light intensity	The average severity level (-)	Number of observations (-)
Daylight	1.44	269
Twilight	1.42	19
Dark with streetlights	1.93	14

5.2.1.4. Type of cyclist

Besides, nothing could be found in the literature review about the relation between conflict severity at signalised intersections and the type of bicycle (standard bicycle, moped, cargo bike, bike with crate on the front, and a scoot mobile). However, while watching video footage it is found that on average 60.6% of the conflicts caused by cyclists are caused by the “moped” type of bicycle, while in all the conflicts observed up to a PET value of 10 seconds in TrafXSafe only 28.6% of the cyclist involved in interactions with motorized vehicles were mopeds. In the video footage is seen that a lot of scooters violate red streetlights. As can be seen in Table 14, the average severity level of conflicts in which mopeds are involved is higher than conflicts in which only standard bicycles are involved. It should be noted that the number of observations for cargo bikes, bikes with crates and scoot mobiles is low, which makes this information not useful for drawing reliable conclusions.

Table 14 - Average severity level and number of observations for different types of cyclists

Type of cyclist	The average severity level (-)	Number of observations (-)
Moped	1.61	138
Standard bicycle	1.30	145
Cargo bike	1.73	15
Bike with crate	1.50	2
Scootmobil	1.00	2

5.2.1.5. Traffic offences – Cyclist through red, motorized vehicle through red, and wrong lane

Furthermore, it is also observed that the type of traffic offence influences the severity of conflicts. As shown in Table 15, the average severity level is lower when a motorized vehicle violates a red or orange traffic light than when a cyclist violates a red traffic light. This can partly be explained by the fact that motorized vehicles have a lower speed when they are crossing the just red or orange light than when a cyclist violates a red or orange traffic light. Besides, when motorized vehicles violate the red or orange traffic lights, it is often the case that the cyclist stands still. Which causes the probability of a crash to be small. On the contrary, if a cyclist violates the red or orange light, most of the time the motorized vehicles have a high speed and so does the cyclist, which makes the probability and the consequences of a conflict higher. Furthermore, it is seen in the video footage that most cyclists that violate the red streetlight are the impatient type of cyclists, which are cyclists that stop and wait for a red light, but still ride through the red light when they must wait too long (see Paragraph 3.3).

Table 15 - Average severity level for different types of traffic offences

Type of traffic offence	The average severity level (-)	Number of observations (-)	Average speed motorized vehicles (km/h)	Average speed cyclists (km/h)
Cyclist violates red or orange traffic light	1.90	124	30.2	13.9
Motorized vehicle violates red or orange traffic light	1.08	106	16.4	12.2
Wrong lane	1.24	25	17.2	15.0

Besides, it can be concluded that the type of traffic offence made by the cyclist or motorized vehicle is related to the scenario and hence influences the severity of the conflict. This can be caused by, among other things, the settings of the traffic lights. For instance, in the scenario of “Westbound through bike - Westbound right turn motorized vehicle” the most occurring traffic violation is motorized vehicles driving through red/ orange traffic lights (85.9%). While in the scenario of “Eastbound through bike – Northbound through motorized vehicle” most of the traffic violations are made by cyclists driving through red (93.0%). Therefore, the average severity level for “Westbound through bike - Westbound right turn motorized vehicle” (average severity level of 1.14) is lower than for "Eastbound through bike – Northbound through motorized vehicle” (average severity level of 2.21).

5.2.1.6. Cyclist from standstill

Furthermore, as can be seen in Figure 24, the most severe conflicts occur when the cyclists are not coming from a standstill. In the data obtained from the video footage, it can be seen that 90% of the conflicts with a severity level of 3, cyclists are not coming from a standstill. While for the less severe conflicts with a severity level of 1 or 2, a lower percentage of cyclists come from a standstill.

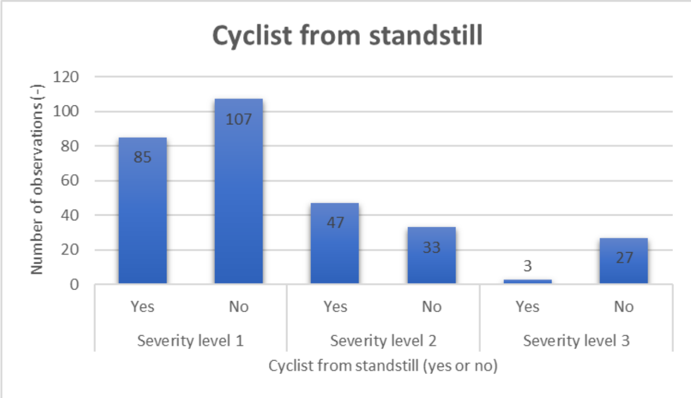

Figure 24 - Number of cyclists from standstill for different severity levels

5.2.1.7. Cycling in groups or alone

Also, it can be found that cycling in groups, in duos or alone also results in different averages for the severity levels of conflicts (see Table 16). In general, it is seen that when cyclists drive alone the severity level of the conflicts is higher than when the cyclist drive in duos or groups. This can be caused by the fact that when cyclists violate red traffic lights they drive most often alone and this type of traffic violation results in a high severity level (see Table 15). However, it can also be caused by other aspects such as the fact that traffic intensity can influence how often cyclist drives in groups. In this case, the traffic intensity can also impact the severity of the conflicts.

Table 16 - Average severity level for different cycling conditions

Cycling condition	The average severity level (-)	Number of observations (-)
Cyclist drives in groups	1.28	25
Cyclist drives in duo's	1.19	32
Cyclist drives alone	1.52	245

5.2.1.8. Order crossing cyclist and motorized vehicle

Lastly, it is seen that the average severity level does not differ for the order in which cyclists and motorized vehicles cross each other. For both orders of crossing, the average severity level is 1.1.

5.2.2. Results multinomial logistic regression model

In this paragraph, the results of the multinomial logistic regression model are given. First of all, it is shown if all the assumptions for the logistic regression model are met. Subsequently, the results of the model are interpreted. Lastly, it is checked how well the model predicts the severity level of conflicts based on the different factors included in the model.

5.2.2.1. Assumptions

As discussed in Paragraph 4.2, five assumptions should be tested before making the model. First of all, it should be checked whether the dependent variable is measured at a nominal level. In this model the dependent variable is the severity level of conflicts which is measured in four categories:

- Safety level 1; is an undisturbed conflict which indicates a safe situation
- Safety level 2; is a potential conflict which indicates a potentially slightly dangerous situation
- Safety level 3; is a slight conflict which indicates a dangerous situation
- Safety level 4; is a serious conflict which indicates an extremely dangerous situation

It can be concluded that these safety levels are measured at a nominal scale which means that the first assumption is met.

Secondly, the assumption should hold that the independent variables are continuous, ordinal or nominal, which is the case for all the independent variables, so this assumption is also met. Furthermore, all the observations are independent of each other which means that the assumption that the observations should be independent also holds.

Lastly, it should be checked whether there is multicollinearity between the independent variables. As discussed in the methodology (see Paragraph 5.2), the independent variables is checked on multicollinearity with the Pearson coefficient. In Figure 25, the Pearson coefficients are shown for all combinations of the independent variables. As discussed in the methodology (see Paragraph 5.2), it is chosen to not take into account variables with a Pearson coefficient higher than 0.70 and lower than -0.70. As can be seen in Figure 25, the independent variable "Who breaks the rules" is highly correlated with "Red light violation cyclist" and "Red light violation motorized vehicle", which makes sense since these two variables determine who breaks the rules (motorized vehicles or cyclists). Therefore, the variable "Who breaks the rules" is not considered in the multinomial logistic regression model.

	Safety indicator value (PET)	Speed motorized vehicle	Speed cyclist	Cyclist from standstill	Light intensity	Type of cyclist	Cycling in group	Peak hours	Red light violation cyclist	Wrong lane	Order passing motorized vehicle and cyclist	Red light violation motorized vehicle	Who breaks the rules	Traffic intensity
Safety indicator value (PET)	1,00													
Speed motorized vehicle	0,17	1,00												
Speed cyclist	0,06	0,08	1,00											
Cyclist from standstill	-0,04	0,08	-0,61	1,00										
Light intensity	0,15	0,15	0,07	-0,04	1,00									
Type of cyclist	0,13	0,24	0,38	-0,08	0,06	1,00								
Cycling in groups	-0,08	-0,26	-0,23	0,18	-0,03	-0,10	1,00							
Peak hours	0,12	0,00	0,05	0,00	0,21	0,05	-0,04	1,00						
Red light violation cyclist	-0,11	-0,62	-0,02	-0,09	-0,25	-0,22	0,21	-0,02	1,00					
Wrong lane	0,15	0,17	-0,06	0,17	0,07	0,15	0,02	0,07	-0,25	1,00				
Order passing motorized vehicle and cyclist	0,19	0,20	-0,19	0,40	0,03	0,21	0,06	0,09	-0,09	0,32	1,00			
Red light violation motorized vehicle	-0,02	0,46	0,20	-0,13	0,15	0,10	-0,28	-0,07	-0,61	-0,22	-0,26	1,00		
Who breaks the rules	0,09	0,56	0,22	-0,04	0,18	0,25	-0,28	0,00	-0,73	0,32	0,00	0,75	1,00	
Traffic intensity	-0,08	-0,22	-0,04	0,03	-0,63	0,03	0,05	-0,33	0,25	-0,08	-0,07	-0,14	-0,20	1,00

Figure 25 - Correlation between factors that possibly influence the severity of conflicts

5.2.2.2. *Interpretation of model*

As discussed above, the independent variable "who breaks the rules" is not considered in the multinomial regression model due to a high correlation with other independent variables. All other independent variables shown in the correlation analysis (see Figure 25) are considered in the multinomial regression model.

After running the multinomial regression model for all these independent variables, SPSS gives the following warning: "There is possibly a quasi-complete separation in the data. Either the maximum likelihood estimates do not exist or some parameter estimates are infinite.". This warning is caused by the fact that for at least one group of the dependent variable, there is a zero frequency for at least one category of an independent variable (Lu, 2016). In this case, there is a zero frequency of red-light violations by motorized vehicles in the severity level 3. According to the literature, this problem is in most cases the result of a small sample size and can be solved by increasing the sample size (Lu, 2016). However, due to time constraints, it is not possible to obtain more data. Therefore, it is chosen to take the red-light violation of motorized vehicles not into account in the multinomial logistic regression model.

After excluding the independent variable 'red light violation of motorized vehicles' from the model, the model did not give any serious warnings anymore. The full results of the multinomial logistic regression model are given in Appendix C.2. The model made in SPSS fits the data well according to the Model Fitting information and the Goodness-of-Fit test since the Deviance and the Pearson give good results. In Table 17, for all categorical data, it is shown which categories are used in the model and which category is the reference category.

Table 17 - Categorical data in the model

Categorical data in the model		
		Number of observations
Severity level	One*	192
	Two	80
	Three	30
Cyclist from standstill	Yes	135
	No*	167
Light intensity	Daylight	269
	Dark with streetlights	14
	Twilight*	19
Type of cyclist	Moped	138
	Standard bicycle*	164
Cycling in alone	Alone	245
	Group*	57
Peak hours	Yes (07:00-09:00 & 16:00-18:00)	79
	No*	223
Red light violation cyclist	Yes	124
	No*	178
Wrong lane	Yes	23
	No*	279
A motorized vehicle crosses before a cyclist	Motorized vehicle before the cyclist	216
	Cyclist before motorized vehicle*	86
* Reference category in the model		

As shown in Table 18, only the independent variables 'motorized vehicle speed', 'cycling alone', and 'cyclist from standstill' are statistically significant in the model (confidence level of 95%). It should be noted that when the speed of the motorized vehicles would not be taken into account in the model, this would have led to different results. Eliminating the motorized vehicle speed from the model would result in worse predictions of the severity of conflicts, which makes sense since the speed of motorized vehicles is used to predict the severity of a conflict (see Appendix C.1) and the speed of motorized vehicles also has relatively the highest impact on the severity of conflicts in the model as shown in Figure 26. Also, the model is run for fewer variables and different combinations of the variables described above, but all these models led to a worse prediction of the severity level. Furthermore, the model is also run with the logarithm of the traffic intensity, however, this also did not lead to better results. Besides, factors which were not statistically significant were eliminated one by one from the model, starting with the parameter with the lowest statistical significance, which did not lead to improvements in the number of correctly predicted severity levels.

Table 18 - Likelihood ratio tests results model SPSS

Likelihood Ratio Tests				
Effect	**Model Fitting Criteria**	**Likelihood Ratio Tests**		
	-2 Log Likelihood of Reduced Model	**Chi-Square**	**df**	**Sig.**
Intercept	173.301[a]	0.000	0	.
Safety indicator value (PET)	177.348	4.047	2	0.132
Speed cyclist (km/h)	176.877	3.577	2	0.167
Traffic intensity (vehicles/hour)	173.319	0.018	2	0.991
Motorized vehicle speed (km/h)	373.153	199.852	2	<0.001
Cyclist from standstill	216.804	43.503	2	<0.001
Light intensity	176.375	3.074	4	0.545
Type of cyclist	176.459	3.158	2	0.206
Cycling in alone	180.871	7.571	2	0.023
Peak hours	173.666	0.366	2	0.833
Red light violation cyclist	176.006	2.705	2	0.259
Wrong lane	176.759	3.458	2	0.177
A motorized vehicle crosses before a cyclist	174.826	1.525	2	0.466

The parameter estimates of the final model are shown in Table 19. For all these independent variables, it is explained if a relationship can be seen between these variables and the severity level of a conflict. Since only the independent variables 'motorized vehicle speed', 'cycling in alone', and 'cyclist from standstill' are statistically significant in the model, the focus is mainly on these parameters.

Table 19 - Parameter estimate table multinomial logistic regression model SPSS

Parameter estimates				
The severity level is three[a]	**B**	**Std. Error**	**Sig.**	**Exp(B)**
Intercept	-12.909	4.194	0.002	
Safety indicator value (PET)	-2.268	1.189	0.056	0.104
Speed cyclist (km/h)	-0.196	0.109	0.072	0.822
Traffic intensity (vehicles/hour)	0.000	0.001	0.930	1.000
Motorized vehicle speed (km/h)	0.733	0.100	<0.001	2.082
Cyclist from standstill	-6.493	1.356	<0.001	0.002
Light intensity is daylight compared to twilight	-0.740	1.732	0.669	0.477
Light intensity is dark with streetlights compared to twilight	-3.036	2.265	0.180	0.048
The type of cyclist is moped compared to a standard cyclist	0.111	1.115	0.921	1.117
Cycling alone	-2.478	1.676	0.139	0.084
Peak hours	0.385	1.008	0.703	1.469
Red light violation cyclist	1.557	1.281	0.224	4.743
Wrong lane	3.537	1.862	0.057	34.373
A motorized vehicle crosses before a cyclist	0.870	1.236	0.481	2.388
The severity level is two[a]	**B**	**Std. Error**	**Sig.**	**Exp(B)**
Intercept	-8.620	2.087	<0.001	
Safety indicator value (PET)	-0.642	0.603	0.287	0.526
Speed cyclist (km/h)	-0.035	0.055	0.523	0.966
Traffic intensity (vehicles/hour)	0.000	0.001	0.962	1.000
Motorized vehicle speed (km/h)	0.443	0.065	<0.001	1.557
Cyclist from standstill	-1.401	0.725	0.053	0.246
Light intensity is daylight	0.527	1.039	0.612	1.694
Light intensity dark with streetlights	-1.172	1.454	0.420	0.310
The type of cyclist is moped compared to a standard cyclist	0.941	0.601	0.117	2.563
Cycling alone	-2.029	0.754	0.007	0.132
Peak hours	0.393	0.650	0.545	1.482
Red light violation cyclist	0.934	0.611	0.126	2.546
Wrong lane	0.101	1.043	0.923	1.106
A motorized vehicle crosses before a cyclist	-0.348	0.645	0.590	0.706
a. Reference category is: One				
The reference categories for the categorical data can be found in Table 17				

However, the regression coefficients in Table 19 are measured in different units, which makes it hard to compare the regression coefficients. Therefore, the standardized regression coefficients are calculated, as discussed in the methodology, to solve this problem (see Paragraph 5.2). The standardized regression coefficients are shown in Table 20 and Figure 26. As can be seen in Table 20 and Figure 26, the motorized vehicle speed, cyclists from a standstill and if cyclists are driving in groups are most important in the logistic regression model. However, it should be noted that only the independent variables ‘motorized vehicle speed’, ‘cycling alone’, and ‘cyclist from standstill’ are statistically significant.

Table 20 - Standardized regression coefficients

Factors	Standardized regression coefficient Severity level 2 compared to reference severity level 1	Standardized regression coefficient Severity level 3 compared to reference severity level 1
Safety indicator value (PET)	-0.659	-1.572
Speed cyclist (km/h)	-0.455	-1.745
Traffic intensity	0.012	0.008
Motorized vehicle speed (km/h)	8.457	9.651
Cyclist from standstill	-1.536	-4.645
Type of cyclist	1.026	0.079
Cycling in alone	-1.960	-1.481
Peak hours	0.377	0.245
Red light violation cyclist	0.982	1.032
Wrong lane	0.063	1.465
A motorized vehicle crosses before a cyclist	-0.347	0.587

Figure 26 - Standardized regression coefficients

Motorized vehicle speed

It can be concluded that the higher the speed of the motorized vehicle is the higher the severity level of a conflict will be. This makes sense since the severity level of the conflicts is partly determined by the speed that the motorized vehicle is driving. Furthermore, this finding is in line with the literature review in Paragraph 3.3, which shows that the higher the speed, the higher the severity of a conflict will be. If the speed of the motorized vehicle increases by 1 km/h, a motorized vehicle is 2.082 times more likely to get involved in a conflict with a severity level of 3 compared to a severity level of 1 and the motorized vehicle is 1.557 times more likely to get involved in a conflict with a severity level of 2 compared to 1 if the speed increases with one unit ($p<0.001$).

Cyclist from standstill

It can be concluded based on the model that if cyclists involved in a conflict come from a standstill the probability of getting involved in a severe conflict will be lower than when the cyclist is already on speed and does not come from a standstill (see Table 19). A cyclist coming from a standstill is 0.002 times less likely to get involved in a conflict with a severity level of 3 compared to a severity level of 1 than a cyclist that is not coming from a standstill ($p<0.001$). This finding is in line with the finding of the descriptive statistics (see Paragraph 5.2.1).

Cycling in groups or alone

Furthermore, the independent variable 'cycling in alone' does also give significant results in the multinomial logistic regression model (see Table 18). From the model, it can be concluded that if a cyclist drives alone, the cyclist is 0.030 times less likely to get involved in a conflict with a severity level of 2 compared to a severity level of 1 compared to a cyclist driving in a group ($p=0.007$).

Type of cyclist

Furthermore, from the model, no significant results can be found for the factor 'type of cyclist' (see Table 19). However, in the descriptive statistics part (see Paragraph 5.2.1.), it could be seen that in general, the moped drivers were more likely to be involved in a severe conflict than cyclists with a standard bicycle. Although the results of the model are not significant, the results of the model also show that mopeds drivers are more likely to get involved in severe crashes compared to cyclists with a standard bicycle. Furthermore, if the speed of the motorized vehicle would not be considered in the model, the type of cyclist would give a significant result in the model (see Appendix C.1).

Red light violation cyclists

In the model, no significant results are found for the independent variable 'red light violation of cyclists'. However, in the descriptive statistics part it is shown that if cyclists violate a red traffic light, the cyclists are more likely to get involved in a severe crash. Although the independent variable 'red light violation cyclists' does not show a significant result in the model, the model shows that if a cyclist crosses a red traffic light the cyclist is more likely to get involved in a severe conflict than a cyclist that does not cross a red traffic light (see Table 19). Furthermore, if the speed of the motorized vehicle would not be considered in the model, the independent variable 'red light violation of cyclists' would give a significant result in the model (see Appendix C.1).

Safety indicator value (PET)

The results obtained for the independent variable 'PET' in the model are not significant, so nothing can be said about this variable with high confidence. This is in line with the results found in Paragraph 5.1, where with the help of an ANOVA test the conclusion was drawn that the mean PET did not significantly differ for the different severity levels. Besides, this result is also consistent with the literature which says that the PET on its own is not a good indicator of the severity of a conflict (Jiang, et al., 2020)(see Paragraph 3.2).

Speed cyclist

The same holds for the speed of cyclists as for the safety indicator. The result for this independent variable is not statistically significant in the multinomial logistic regression model, so nothing can be said about the relationship between the speed of the cyclist and the severity of conflicts between cyclists and motorized vehicles. This is also in line with the results of the ANOVA test done in the descriptive description part where no statistically significant difference could be seen in the mean speed of the cyclist for different severity levels (see Paragraph 5.2.1).

Traffic intensity

The results obtained for the independent variable 'traffic intensity' is not significant (see Table 18), as a result, nothing can be said about the relation between traffic intensity and the severity of a conflict based on the model. However, in the descriptive statistics part a statistically significant difference could be seen in average traffic intensity for the different severity levels which can indicate a relation between the traffic intensity and the severity of conflicts (see Paragraph 5.2.1). This result is in line with the literature review in which there is no consensus on if the traffic volume influences the severity of conflicts (Retallack & Ostendorf, 2020) (see Paragraph 3.3).

Peak hours

The result for peak hours is not statistically significant in the model (see Table 18), therefore, no relation can be found between peak hours and the severity of conflicts based on the data available.

Wrong lane

The results obtained for the wrong lane are not statistically significant (see Table 18), as a result, no relation can be found between cyclists taking the wrong lane and the severity of conflicts. It should be noted that only a few observations are available in which vehicles take the wrong lane (25 observations), which makes it difficult to draw conclusions based on this data.

Order of crossing cyclist and motorized vehicle

No relation could be found between the order of crossing between cyclists and motorized vehicles and the severity of conflicts since the model did not produce statistically significant results for this independent variable (see Table 18). This finding is in line with the finding of the descriptive statistics part where also no relationship could be found between the severity of conflicts and the order of crossing between cyclists and motorized vehicles (see Paragraph 5.2.1).

Light intensity

The model also does not give significant results for the variable 'light intensity', which means that no relation can be found between light intensity and the severity of conflicts based on the used multinomial logistic regression model results (see Table 18). It should be noted that this can be caused by the low number of observations and the fact that the video footage is made in summer. During this summer period, the period in which it is dark outside is short, which means that only a limited number of observations are available for a situation in which it is dark.

5.2.2.3. Model performance

As can be seen in Table 21, the model predicts in 87.4% of the cases the correct severity class. The model predicts the severity class by selecting the severity level with the highest probability calculated by the model for every conflict. Subsequently, the model compares the predicted severity level for the conflict with the actual severity level of the conflict in the data. As can be seen in Table 21, the model works better for predicting severity level one compared to severity levels two and three. However, the data set used is small and it should also be tested for other data if the model works correctly to validate the model. However, such a data set is not available which means that it cannot be tested if this model also works for a larger dataset or data collected at other intersections.

Table 21 - Classification table multinomial logistic regression model SPSS

Classification				
Observed	**Predicted**			
	One	**Three**	**Two**	**Percent Correct**
One	182	0	10	94.8%
Three	0	23	7	76.7%
Two	15	6	59	73.8%
Overall Percentage	65.2%	9.6%	25.2%	87.4%

Lastly, to validate the model, it is tested if the results of the model are in line with the literature, which is the case. For instance, in the model no clear relation could be found between the traffic intensity and the severity of conflicts, in multiple other studies also no clear relationship between traffic volume and the severity of conflicts could be found (Retallack & Ostendorf, 2020). Besides, the result of the model that shows that the PET does not fully indicate the severity of a conflict is also consistent with the literature which says that the PET on its own is not a good indicator of the severity of a conflict (Jiang, et al., 2020). However, not for all the variables literature could be found, so these parameters were looked at with a logical sense and it could be concluded that odd ratios that came out of the model were logical.

6. Discussion

As shown in the result section (see Chapter 5), it can be concluded that the PET measure on its own does not always give a good indication of the severity of a conflict. Furthermore, it could be concluded that the factors ‘motorized vehicle speed’, ‘cycling alone’, 'type of cyclist', 'red light violation cyclist' and ‘cyclist from standstill’ can influence the severity of conflicts at intersections. However, the methods in this study have some shortcomings that will influence the results of the research. Therefore, the limitations and assumptions made in the research are discussed in this section.

6.1. Data

The findings of this study are based on a small number of observations. As a result, it is not possible to say with certainty which factors further influence conflict severity. For instance, only a few observations are available in which vehicles drive in the wrong lane (25 observations). Based on this number of observations it cannot be found if this type of traffic offence influences the severity of conflicts. However, if more data would be available, it will maybe lead to different results. Furthermore, on two occasions an ambulance was observed in the video footage, driving across the intersection which caused a conflict to happen, but two observations are not enough to determine whether ambulances have an impact on the severity of conflicts at signalized intersections. Another issue is that the video data is collected within one week time in the summer, during that week the weather conditions were good, and it was only dark outside for a very short time during the day. Therefore, it cannot be examined if the weather conditions and light intensity have an impact on the severity of conflicts. To say with more certainty which factors impact conflict severity, more observations need to be made over a longer period for multiple intersections for a larger range of PET values.

Furthermore, the video footage used in this research is made at one intersection in the Hague. Based on the information coming from one intersection, general conclusions can be drawn for that intersection. To draw a conclusion about which factors influence the severity of conflicts at signalised intersections with more certainty, multiple intersections should be looked at. When looking at multiple intersections, it is also possible to determine whether the design of the intersection affects the conflict severity between motorized vehicles and cyclists.

Lastly, it was impossible to find the exact relation between conflicts and crashes due to the limitations in crash and conflict data at the intersection between the Calandstraat and the Waldorfstraat. Crash data and conflict data on more intersections is needed to say with more certainty what the relation between the crashes and conflicts is.

6.2. Determination severity level

Besides, the severity of conflicts is determined in quite a subjective manner since there is no consensus in the literature on how to determine the severity of a conflict. However, it would be better to find a method that can determine the severity level of a conflict in a more objective manner. First of all, this makes it easier to repeat this study and also the results will be less biased by the researchers' own perspective on what a severe conflict is.

6.3. Interrelation between factors

Lastly, there are a lot of factors that can influence the severity of conflicts between cyclists and motorized vehicles at intersections. Some of these factors may not be directly visible and are therefore not included in this research. However, these factors may be correlated with factors included in the research. Therefore, it may be the case that the research shows that a certain factor influences the severity of a conflict while in reality another underlying factor causes this. Furthermore, there are a lot of factors that are interrelated which makes it difficult to obtain results. Due to all these uncertainties, the results should be treated critically.

7. RECOMMENDATIONS

As discussed in Chapter 6, there are some limitations in this research which influence the results. Therefore, in this chapter recommendations are given for future research concerning data collection, the method to define the severity of conflicts and how to deal with interrelated factors. Furthermore, recommendations are given in this paragraph to policymakers.

7.1. DATA COLLECTION

The data for this research was collected by SWOV in a pilot study at three intersections over 1 week. However, this is too little data to determine exactly what factors influence the severity of conflict at intersections. The influence of factors on the severity of conflicts at intersections such as intersection design and weather conditions cannot be determined based on only this video footage. Therefore, it is recommended to gather more video footage of different intersections under different conditions to investigate what factors influence the severity of conflicts.

Furthermore, it is recommended in future research to use data from more intersections to investigate the relation between the severity of conflicts and crashes at signalised intersections. This will give a better insight into the relationship between conflicts and crashes.

Lastly, some features such as the colour of the traffic light or the difference between normal and electric bikes cannot be seen well in the video footage due to the view angle of the camera and the large distance of the camera to the intersections. Therefore, it is also recommended to record information about the signal timing of the traffic lights and the type of bike in a different manner. For instance by installing an extra camera lower to the ground to see these kinds of characteristics better. However, this can cause privacy issues for which a solution should be found.

7.2. DETERMINATION SEVERITY LEVEL

Furthermore, it is recommended to use one or more indicators in addition to the PET in the software to determine the severity of conflicts since in this research it is shown that the PET does not always fully reflect the severity of a conflict. It is recommended to use a method such as the Conflict Index (see literature review in Paragraph 3.2.2) in addition to the PET, in which the researchers do not have to identify subjectively the possible consequences of a conflict to determine the severity level of a conflict. This was not possible in this research since there was no information available on the mass of the vehicles observed in the video footage. However, if the mass of the vehicles involved in conflicts would be available in future research, it would be interesting to use a method such as the Conflict Index to determine the severity level of a conflict.

7.3. INTERRELATION BETWEEN FACTORS

Lastly, a lot of factors that influence the severity of conflicts at signalised intersections are interrelated with each other. Therefore, it is difficult to say with certainty which factors influence the severity of conflicts. To solve this problem, it would be interesting to look at different intersections where only one factor is changed and all other factors stay the same, to see how this factor influences the severity of conflicts at intersections. However, it can be challenging and time-consuming to do this for all the factors. Due to ethical concerns, it is for instance not possible to exclude certain road users during the investigation of the effect of the type of road user on the number of conflicts. However, it is possible to make changes in intersection design to investigate the impact of the intersection design on traffic safety. However, this cost a lot of money and is therefore also not always feasible. Therefore, it is recommended for future research to investigate how different factors are related to each other, by comparing the different characteristics and conflict data of multiple intersections.

7.4. POLICY MAKING

As shown in this research, the factors ‘motorized vehicle speed’, ‘cycling alone’, 'type of cyclist', 'red light violation cyclist' and ‘cyclist from standstill’ can influence the severity of conflicts at signalised intersections. Therefore, it is recommended to policymakers to take measures to reduce the speed of motorized vehicles at signalised intersections as much as possible to improve traffic safety at the intersections. Furthermore, it is recommended to take measures to destimulate moped drivers to violate traffic rules, since it is seen in this research that mopeds often violate traffic rules, which results in unsafe situations. In addition, it is recommended to policymakers to reduce the waiting time for cyclists as much as possible at signalised intersections since it is shown in this research that a lot of cyclists that have to wait long for a red traffic light will violate the red traffic light which decreases the traffic safety at signalised intersections.

8. CONCLUSION

This research aimed to get a better understanding of what kind of factors influence the severity of conflicts between cyclists and motorized vehicles at signalised intersections so that this information can be used in the long term to improve traffic safety at signalised intersections between cyclists and motorized vehicles. Therefore, in this conclusion, answers are given to two sub-questions to answer the main question and to subsequently reach the research aim. In this research, several factors are found that influence the severity of conflicts at signalised intersections between cyclists and motorized vehicles. This knowledge can be taken into account by policymakers when making requirements for intersection designs to make intersections as safe as possible.

Subquestion 1: How can the severity of conflicts at signalised intersections be classified by using TTC or PET?
It can be concluded that the PET value by itself does not fully indicate the severity of a conflict (see Paragraph 5.1). At signalised intersections, a traffic rule is almost always broken when the PET is below 2 seconds. The type of traffic offence that is made has a great influence on the severity of the conflict. If the road user intentionally breaks a rule such as running a red light, this can lead to a low PET value while the conflict is not serious. However, the results show that when the PET is below 1.5 seconds, the chance of a conflict becoming a crash is higher than for a PET value above 1.5 seconds. Therefore, it can be concluded that the PET can help to identify if a conflict occurs but not does fully indicate the severity of a conflict.

Subquestion 2: What factors influence the severity of conflicts at signalised intersections?
Based on the results of the multinomial logistic regression model shown in Paragraph 5.2, it can be concluded that the factors ‘motorized vehicle speed’, ‘cycling alone’, and ‘cyclist from standstill’ are related to the severity of conflicts. However, from the descriptive statistics part, it can also be concluded, that ‘red light violation by cyclist’ and ‘the type of cyclist’, can influence the severity of conflicts.

If the speed of the motorized vehicle becomes higher the probability of a severity conflict will also become higher. Furthermore, cyclists that drive in groups are more likely to get involved in a severe conflict than cyclists that drive alone. Besides, if a cyclist comes from a standstill the cyclist is less likely to get involved in a severe conflict. Moreover, the type of cyclist also influences the severity of a conflict. In general, road users with a moped are more likely compared to standard cyclists to get involved in a severe conflict. It is also found that relatively a lot of mopeds are involved in conflicts compared to standard cyclists. Lastly, it can be concluded that if a cyclist crosses a red light this increases the probability of a severe conflict considerably.

For all the other factors investigated in this study (safety indicator value, traffic intensity, speed cyclist, light intensity, wrong lane, red light violation car and the order of crossing between cyclist and motorized vehicle), no relation is found between the factor and the severity of conflicts. This can be caused by several things. First of all, it can be caused by the fact that too limited data is available. Another option is that there is simply no relationship between the factors and the severity level of a conflict. Lastly, it can be caused by the fact that only one intersection is considered with certain characteristics for which no relation between these factors and the severity level of conflicts can be found while maybe for another intersection there would be a relation between the factors and the severity levels of conflicts.

Main question: What kind of factors influence the severity of conflicts at intersections between cyclists and motorized vehicles at signalised intersections?
It can be concluded that there is no consensus on how to determine the severity level of a conflict. In the literature review, different methods are found that researchers use to determine the severity of a conflict. In some studies, the PET value is used to determine the severity of a conflict. However, from this research, it can be concluded that the severity of a conflict cannot fully be determined by solely using the PET value.

In this report, the way of determining the severity level of a conflict was inspired by the Dutch Traffic Conflict Technique. The severity level assigned to each conflict with this method is used to investigate which factors influence the conflict severity between cyclists and motorized vehicles at signalised intersections. Partly due to the limited data available, a relation could not be found between all factors and the severity of a conflict. However, it is found that the factors ‘motorized vehicle speed’, ‘cycling alone’, 'cyclist from standstill', 'type of cyclist' and 'red light violation cyclist' influence the severity level of conflicts. Furthermore, it can be concluded that more data is needed to determine whether the other factors also have an impact on the conflict severity between cyclists and motorized vehicles at signalised intersections.

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APPENDIX A. TYPES OF CONFLICTS OBSERVED IN TRAFXSAFE

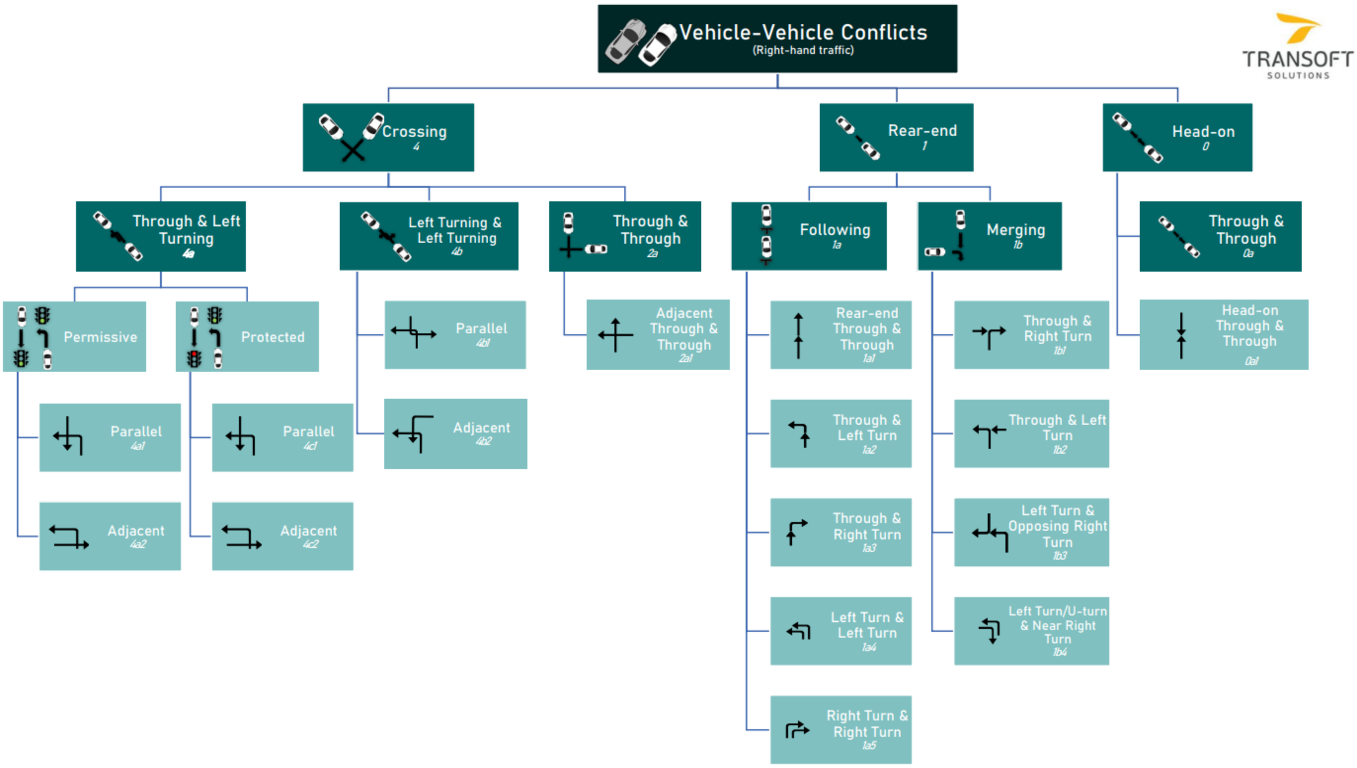

Figure 27 - Vehicle-Vehicle conflicts

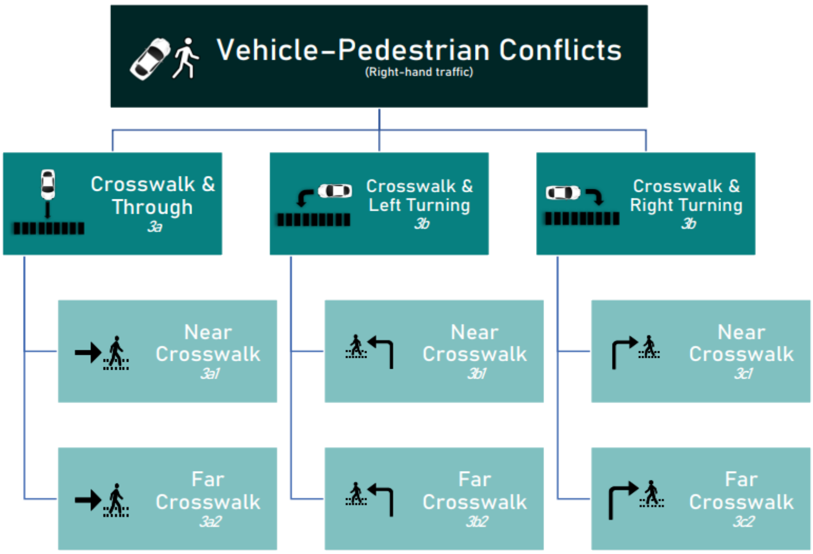

Figure 28 - Vehicle-Pedestrian conflicts

APPENDIX B. ANOVA TESTS

B.1. SPEED MOTORIZED VEHICLES FOR DIFFERENT SCENARIOS

In Excel, a one-way ANOVA test is done to check whether there is a significant difference in the mean speed driven by motorized vehicles during a conflict (in km/h) for different scenarios. As can be seen in Table 22 and Table 23, the F value is higher than F critical and the P-value is lower than 0.05. Therefore, it can be concluded that there is a significant difference in mean motorized vehicle speed for different scenarios.

Table 22 - Summary of data used in the ANOVA test for speed and different scenarios

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Eastbound through bike – Eastbound left turn car	27	741.76	27.47259	17.03244
Eastbound through bike – Northbound through car	57	2054.736	36.048	72.30181
Eastbound through bike – Westbound right turn car	108	2008.352	18.59585	16.81474
Westbound through bike – Eastbound left turn car	9	233.776	25.97511	64.61818
Westbound through bike – Northbound through car	27	904.24	33.49037	29.13274
Westbound through bike – Westbound right turn car	74	1316.496	17.79049	16.25172

Table 23 - Output ANOVA test for speed in different scenarios

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	17073.3	5	3414.659	115.4907	2.08E-67	2.244495
Within Groups	8751.695	296	29.56654			
Total	25824.99	301				

B.2. MAXIMUM SPEED FOR DIFFERENT SEVERITY LEVELS

In Excel, a one-way ANOVA test is done to check whether there is a significant difference in the mean driven speed by motorized vehicles during a conflict (in km/h) for different severity levels. As can be seen in Table 24 and Table 25, the F value is higher than F critical in this case and the P-value is lower than 0.05. Therefore, it can be concluded that there is a significant difference in mean motorized vehicle speed for different severity levels.

Table 24 - Summary of data used in the ANOVA test for speed and different severity levels

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Severity level 1	192	3564.016	18.56258	19.50802
Severity level 2	80	2533.104	31.6638	49.39693
Severity level 3	30	1162.24	38.74133	44.91515

Table 25 - Output ANOVA test for speed and different severity levels

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	16894.06	2	8447.031	282.7995	1.15E-69	3.025949
Within Groups	8930.929	299	29.86933			
Total	25824.99	301				

B.3. PET VALUES FOR DIFFERENT SEVERITY LEVELS

Furthermore, in Excel, a one-way ANOVA test is done to check whether there is a significant difference in the mean PET values for different severity levels. As can be seen in Table 26 and Table 27, the F value is lower than F critical in this case and the P-value is higher than 0.05. Therefore, it can be concluded that there is no significant difference in the mean PET values for different severity levels.

Table 26 - Summary of data used in the ANOVA test for PET values and different severity levels

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Severity level 1	192	231.12	1.20375	0.246972
Severity level 2	80	106.04	1.3255	0.13921
Severity level 3	30	36.56	1.218667	0.12135

Table 27 - Output ANOVA test for PET values and different severity levels

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.848861	2	0.42443	2.057188	0.129618	3.025949
Within Groups	61.68843	299	0.206316			
Total	62.53729	301				

B.4. PET VALUES FOR DIFFERENT PROBABILITIES THAT A CONFLICT WILL DEVELOP A COLLISION

Just as in Appendix A.1. A.2 and A.3, a one-way ANOVA test is done in Excel to check whether there is a significant difference in the mean PET values for different probability levels that a conflict will develop a collision (high, medium, low). As can be seen in Table 28 and Table 29, the F value is higher than F critical in this case and the P-value (0.008) is lower than 0.05. Therefore, it can be concluded that there is a significant difference in mean PET value for different probability levels that a conflict will develop a crash.

Table 28 - Summary of data used in the ANOVA test for PET values and different probability levels that a conflict will develop a crash

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Probability High	3	4	1.333333	0.130133
Probability Medium	122	139	1.139344	0.182089
Probability Low	177	230.72	1.303503	0.217444

Table 29 - Output ANOVA test for PET values and different probability levels that a conflict will develop a crash

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.974045	2	0.987022	4.872918	0.008269	3.025949
Within Groups	60.56324	299	0.202553			
Total	62.53729	301				

B.5. Speed cyclists for different severity levels

Also, a one-way ANOVA test is done in Excel to check whether there is a significant difference in the mean speed that the cyclists involved in conflicts have for different severity levels. As can be seen in Table 30 and Table 31, the F value is lower than F critical in this case and the P-value is higher than 0.05. Therefore, it can be concluded that there is no significant difference in the mean speed of cyclists for different severity levels.

Table 30 - Summary of data used in the ANOVA test for the speed of cyclists and severity levels

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Severity level 1	192	2593.424	13.50742	38.42178
Severity level 2	80	1106.96	13.837	27.61603
Severity level 3	30	463.424	15.44747	27.20052

Table 31 - Output ANOVA test for the speed of cyclists and severity levels

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	97.92246	2	48.96123	1.420055	0.243326	3.025949
Within Groups	10309.04	299	34.4784			
Total	10406.96	301				

B.6. Traffic intensities for different severity levels

Besides, in Excel, a one-way ANOVA test is done to check whether there is a significant difference in the mean traffic intensity for the different severity levels. As can be seen in Table 32 and Table 33, the F value is higher than F critical in this case and the P-value is lower than 0.05. Therefore, it can be concluded that there is a significant difference in mean traffic intensity for different severity levels.

Table 32 – Summary of data used in the ANOVA test for traffic intensities and different severity levels

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Severity level 1	192	493305	2569.297	235912.6
Severity level 2	80	194684	2433.55	369467.3
Severity level 3	30	69888	2329.6	588931.5

Table 33 – Output ANOVA test for traffic intensities and different severity levels

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2118920	2	1059460	3.468648	0.032419	3.025949
Within Groups	91326241	299	305438.9			
Total	93445161	301				

APPENDIX C. RESULTS OF MULTINOMIAL LOGISTIC REGRESSION MODEL

C.1. RESULTS MODEL EXCLUDING MOTORIZED VEHICLE SPEED SPSS

In this paragraph, the results produced by SPSS for the multinomial logistic regression model excluding the speed of the motorized vehicles are shown.

Table 34 - Case processing summary SPSS multinomial logistic regression model excluding motorized vehicle speed

Case Processing Summary			
		N	Marginal Percentage
Severity level	One*	192	63.6%
	Three	30	9.9%
	Two	80	26.5%
Cyclist from standstill	Yes	135	44.7%
	No*	167	55.3%
Light intensity	Daylight	269	89.1%
	Dark with streetlights	14	4.6%
	Twilight*	19	6.3%
Type of cyclist	Moped	138	45.7%
	Standard bicycle*	164	54.3%
Cycling alone	Alone	245	81.1%
	Group*	57	18.9%
Peak hours	Yes (07:00-09:00 & 16:00-18:00)	79	26.2%
	No*	223	73.8%
Red light violation cyclist	Yes	124	41.1%
	No*	178	58.9%
Wrong lane	Yes	23	7.6%
	No*	279	92.4%
A motorized vehicle crosses before a cyclist	Motorized vehicle before cyclist	216	71.5%
	Cyclist before motorized vehicle*	86	28.5%
Valid		302	100.0%
Missing		0	
Total		302	
Subpopulation		302[a]	
a. The dependent variable has only one value observed in 302 (100.0%) subpopulations.			

Table 35 – Model fitting information SPSS multinomial logistic regression model excluding motorized vehicle speed

Model Fitting Information				
Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	525.024			
Final	373.153	151.870	24	<0.001

Table 36 - Goodness-of-fit SPSS multinomial logistic regression model excluding motorized vehicle speed

Goodness-of-Fit			
	Chi-Square	df	Sig.
Pearson	802.254	578	<0.001
Deviance	373.153	578	1.000

Table 37 - Pseudo R-Square SPSS multinomial logistic regression model excluding motorized vehicle speed

Pseudo R-Square	
Cox and Snell	0.395
Nagelkerke	0.480
McFadden	0.289

Table 38 - Likelihood ratio test SPSS multinomial logistic regression model excluding motorized vehicle speed

Likelihood Ratio Tests				
Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	373.153[a]	0.000	0	.
Safety indicator value (PET in seconds)	375.352	2.198	2	0.333
Speed cyclist	373.395	0.242	2	0.886
Traffic intensity	374.457	1.304	2	0.521
Cyclist from standstill	398.138	24.985	2	<0.001
Light intensity	376.825	3.672	4	0.452
Type of cyclist	379.488	6.335	2	0.042
Cycling alone	374.087	0.934	2	0.627
Peak hours	376.369	3.216	2	0.200
Red light violation cyclist	445.409	72.256	2	<0.001
Wrong lane	373.660	0.507	2	0.776
A motorized vehicle crosses before a cyclist	375.707	2.554	2	0.279
The chi-square statistic is the difference in -2 log-likelihoods between the final model and a reduced model. The reduced model is formed by omitting an effect from the final model. The null hypothesis is that all parameters of that effect are 0.				
a. This reduced model is equivalent to the final model because omitting the effect does not increase the degrees of freedom.				

Table 39 - Parameter estimates SPSS multinomial logistic regression model excluding motorized vehicle speed

Parameter estimates				
Severity level three[a]	**B**	**Std. Error**	**Sig.**	**Exp(B)**
Intercept	-4.916	2.221	0.027	
Safety indicator value (PET)	-0.276	0.604	0.648	0.759
Speed cyclist (km/h)	-0.011	0.056	0.838	0.989
Traffic intensity (vehicles/hour)	0.000	0.001	0.568	1.000
Cyclist from standstill	-2.658	0.751	<0.001	0.070
Light intensity is daylight compared to twilight	1.331	1.048	0.204	3.785
Light intensity is dark with streetlights compared with twilight	1.166	1.279	0.362	3.211
The type of cyclist is moped compared to standard cyclists	0.066	0.610	0.914	1.068
Cycling alone	0.879	1.132	0.437	2.410
Peak hours	0.761	0.592	0.198	2.141
Red light violation cyclist	3.745	0.695	<0.001	42.299
Wrong lane	0.003	1.238	0.998	1.003
A motorized vehicle crosses before a cyclists	0.908	0.642	0.157	2.479
Severity level two[a]	**B**	**Std. Error**	**Sig.**	**Exp(B)**
Intercept	-3.554	1.329	0.008	
Safety indicator value (PET)	0.455	0.379	0.229	1.576
Speed cyclist (km/h)	0.013	0.038	0.727	1.013
Traffic intensity (vehicles/hour)	0.000	0.000	0.260	1.000
Cyclist from standstill	0.463	0.449	0.303	1.589
Light intensity is daylight compared to twilight	1.185	0.740	0.109	3.272
Light intensity is dark with streetlights compared with twilight	0.648	0.959	0.499	1.911
The type of cyclist is moped compared to standard cyclists	0.917	0.380	0.016	2.503
Drive cyclists alone	0.275	0.452	0.544	1.316
Peak hours	0.618	0.386	0.109	1.855
Red light violation cyclist	2.113	0.350	<0.001	8.273
Wrong lane	-0.563	0.842	0.504	0.569
A motorized vehicle crosses before a cyclists	-0.072	0.423	0.866	0.931
a. Reference category is: One				
The reference categories for the categorical data can be found in Table 34				

Table 40 - Classification table SPSS multinomial logistic regression model excluding motorized vehicle speed

Classification				
Observed	Predicted			
	One	Three	Two	Percent Correct
One	173	5	14	90.1%
Three	6	20	4	66.7%
Two	29	8	43	53.8%
Overall Percentage	68.9%	10.9%	20.2%	78.1%

C.2. Results model including motorized vehicle speed SPSS

In this paragraph, the results produced by SPSS for the multinomial logistic regression model including the speed of the motorized vehicles are shown.

Table 41 - Case processing summary SPSS multinomial logistic regression model including speed motorized vehicle

Case Processing Summary			
		N	Marginal Percentage
Severity level	One*	192	63.6%
	Three	30	9.9%
	Two	80	26.5%
Cyclist from standstill	Yes	135	44.7%
	No*	167	55.3%
Light intensity	Daylight	269	89.1%
	Dark with streetlights	14	4.6%
	Twilight*	19	6.3%
Type of cyclist	Moped	138	45.7%
	Standard bicycle*	164	54.3%
Cycling alone	Alone	245	81.1%
	Group*	57	18.9%
Peak hours	Yes (07:00-09:00 & 16:00-18:00)	79	26.2%
	No*	223	73.8%
Red light violation cyclist	Yes	124	41.1%
	No*	178	58.9%
Wrong lane	Yes	23	7.6%
	No*	279	92.4%
A motorized vehicle crosses before a cyclist	Motorized vehicle before cyclist	216	71.5%
	Cyclist before motorized vehicle*	86	28.5%
Valid		302	100.0%
Missing		0	
Total		302	
Subpopulation		302[a]	
a. The dependent variable has only one value observed in 302 (100.0%) subpopulations.			

Table 42 - Model fitting information SPSS multinomial logistic regression model including motorized vehicle speed

Model Fitting Information				
Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	525.024			
Final	173.301	351.723	26	<0.001

Table 43 - Goodness-of-fit SPSS multinomial logistic regression model including motorized vehicle speed

Goodness-of-Fit			
	Chi-Square	df	Sig.
Pearson	325.078	576	1.000
Deviance	173.301	576	1.000

Table 44 - Pseudo R-Square SPSS multinomial logistic regression model including motorized vehicle speed

Pseudo R-Square	
Cox and Snell	0.688
Nagelkerke	0.835
McFadden	0.670

Table 45 - Likelihood ratio test SPSS multinomial logistic regression model including motorized vehicle speed

Likelihood Ratio Tests				
Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	173.301[a]	0.000	0	.
Safety indicator value (PET)	177.348	4.047	2	0.132
Speed cyclist (km/h)	176.877	3.577	2	0.167
Traffic intensity	173.319	0.018	2	0.991
Motorized vehicle speed (km/h)	373.153	199.852	2	<0.001
Cyclist from standstill	216.804	43.503	2	<0.001
Light intensity	176.375	3.074	4	0.545
Type of cyclist	176.459	3.158	2	0.206
Cycling alone	180.871	7.571	2	0.023
Peak hours	173.666	0.366	2	0.833
Red light violation cyclist	176.006	2.705	2	0.259
Wrong lane	176.759	3.458	2	0.177
A motorized vehicle crosses before a cyclist	174.826	1.525	2	0.466
The chi-square statistic is the difference in -2 log-likelihoods between the final model and a reduced model. The reduced model is formed by omitting an effect from the final model. The null hypothesis is that all parameters of that effect are 0.				
a. This reduced model is equivalent to the final model because omitting the effect does not increase the degrees of freedom.				

Table 46 - Parameter estimates SPSS multinomial logistic regression model including motorized vehicle speed

Parameter estimates				
The severity level is three[a]	**B**	**Std. Error**	**Sig.**	**Exp(B)**
Intercept	-12.909	4.194	0.002	
Safety indicator value (PET)	-2.268	1.189	0.056	0.104
Speed cyclist (km/h)	-0.196	0.109	0.072	0.822
Traffic intensity (vehicles/hour)	0.000	0.001	0.930	1.000
Motorized vehicle speed (km/h)	0.733	0.100	<0.001	2.082
Cyclist from standstill	-6.493	1.356	<0.001	0.002
Light intensity is daylight compared to twilight	-0.740	1.732	0.669	0.477
Light intensity is dark with streetlights compared to twilight	-3.036	2.265	0.180	0.048
The type of cyclist is moped compared to a standard cyclist	0.111	1.115	0.921	1.117
Drive cyclist alone	-2.478	1.676	0.139	0.084
Peak hours	0.385	1.008	0.703	1.469
Red light violation cyclist	1.557	1.281	0.224	4.743
Wrong lane	3.537	1.862	0.057	34.373
A motorized vehicle crosses before a cyclist	0.870	1.236	0.481	2.388
The severity level is two[a]	**B**	**Std. Error**	**Sig.**	**Exp(B)**
Intercept	-8.620	2.087	<0.001	
Safety indicator value (PET)	-0.642	0.603	0.287	0.526
Speed cyclist (km/h)	-0.035	0.055	0.523	0.966
Traffic intensity (vehicles/hour)	0.000	0.001	0.962	1.000
Motorized vehicle speed (km/h)	0.443	0.065	<0.001	1.557
Cyclist from standstill	-1.401	0.725	0.053	0.246
Light intensity is daylight	0.527	1.039	0.612	1.694
Light intensity dark with streetlights	-1.172	1.454	0.420	0.310
The type of cyclist is moped compared to a standard cyclist	0.941	0.601	0.117	2.563
Drive cyclist alone	-2.029	0.754	0.007	0.132
Peak hours	0.393	0.650	0.545	1.482
Red light violation cyclist	0.934	0.611	0.126	2.546
Wrong lane	0.101	1.043	0.923	1.106
A motorized vehicle crosses before a cyclist	-0.348	0.645	0.590	0.706
a. Reference category is: One				
The reference categories for the categorical data can be found in Table 41				

Table 47 - Classification table SPSS multinomial logistic regression model including motorized vehicle speed

Classification				
Observed	Predicted			
	One	Three	Two	Percent Correct
One	182	0	10	94.8%
Three	0	23	7	76.7%
Two	15	6	59	73.8%
Overall Percentage	65.2%	9.6%	25.2%	87.4%