School of Transportation Sciences

Master of Transportation Sciences

Master's thesis

Assessing General Vulnerable Road Users' Crossing Behaviour At Undisclosed Green Square Traffic Light Sites And Extrapolating Findings To Disclosed Green Square Traffic Light Sites: A Study Using Drone Technology And Proximal Factors

Loran Reynaerts

Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences, specialization Traffic Safety

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Acknowledgments
During the 2023-2024 academic year, I have written my thesis on the assessment of vulnerable road users’ crossing behaviour at hidden green traffic light cycle intersections in Hasselt, utilising drone technology and proximal factors. A great many people assisted me throughout this process, from its initial conception to its final completion. I would therefore like to express my gratitude to them in this paragraph.

Firstly, I would like to express my gratitude to Professor Dr. Ir. Wim Ectors for his guidance, critical thinking, positive constructive feedback and availability in answering my questions whenever he could. He introduced me to this topic, which I was previously unfamiliar with, and demonstrated its potential for future transportation research.
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Loran Reynaerts
Hasselt, June 7, 2024

Abstract
In 2022, there was a decrease in the number of fatalities on Belgian roads, with 510 lives lost compared to the previous year of 2019 (Statbel, 2023). This is still far away from the target of Vision Zero or zero traffic fatalities and seriously injured by 2050. The drone technology must provide insight into the (potentially dangerous) interaction between different transport modes and the environment (infrastructure). It is the intention to come up with a new method and develop an innovative way to (proactively) research and evaluate infrastructure. The infrastructure evaluated in this research is the measurement of a green traffic light cycle. This intervention allows active road users to receive a green signal simultaneously and can traverse the junction in varied directions at the same time (AWV, n.d.).

The main research question of this paper is: *What is the effect of the infrastructural intervention of a green traffic light cycle, with the aim of improving road safety for road users following the STOP principle, based on drone technology and its proximal factors?*

An excessive literature review was conducted to learn about traffic safety, conflicts, drone research, proximal indicators to support drone research and green traffic light cycles. The next step was to record footage with the help of a drone. Three locations were filmed over a period of 30 minutes. This information was than processed and analysed by the software program Data from Sky (2024) to learn about speed, Origin/Destination matrices, safety analyses based on Time-To-Collision (TTC) - and Post-Encroachment-Time (PET) indicators.

The conclusion of this research and the answer to the main research question is the following: The advantages of green traffic light cycles are underutilized at Dusart, Sint-Truidersteenweg, and Kunstlaan. This leads to conflict points at pedestrian waiting areas rather than intersections. Observations show different conflicts and road users at these waiting areas, potentially extending to intersections if green light benefits, like diagonal crossings, were used. Although literature mentions conflicts among vulnerable road users (VRUs) during green cycles, this research does not confirm it. Most waiting area conflicts are minor. Intersections struggle with clearing motorized traffic, as VRUs begin crossing prematurely. Drone technology analysis revealed misclassification issues, exaggerating incident severity and probability.

Keywords:
Vulnerable Road Users, VRUs, crossing behaviour, Green traffic ligh cycle, pedestrian phase, exclusive pedestrian phase, cycling phase, pedestrian scramble, intersection scramble, diagonal crossing scramble intersection, All-way walk, Scramble crossing, Barnes dance, drone technology, proximal factors, transportation sciences, Vision Zero, system approach, proactive research, infrastructure evaluation, Time-to-Collision, Post-Encroachment Time

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List of abbreviations

AWV: Agency of Roads and Traffic, in Belgium
DFS: Data From Sky
DRAC: Deceleration Rate to Avoid the Crash
DSSM: Deceleration-based Surrogate Safety Meausure
EPP: exclusive pedestrian phases
FOD: Federal Public Service Finance (FOD)
GDP: Gross Domestic Product
IMOB: Institute for Mobility
MIA: Mobility Innovative Approach
NGOs: Non-profit organizations
PET: Post-Encroachment Time
PSD: Proportion of Stopping Distance
SSAM: Surrogate Safety Assessment Model
STOP-principle: Pedestrians, Bicycles, Public Transport, Private mobility
TTC: Time-to-Collision
UAS: Unmanned aircraft system (UAS)
UAV: Unmanned Aerial Vehicle
UTM: Universal Transverse Mercator
VRU(s): Vulnerable Road User(s)

1. Introduction

1.1. Vision Zero and safe system approach

In Belgium the number of traffic deaths is decreasing. In 2019, 56 fatalities per 1 million inhabitants were registered (All for Zero, 2021). This is still higher than the European mean of 51 fatalities per 1 million inhabitants. In Belgium, the vision zero approach is considered as the main target (Flemish Department Mobility and public works, 2021). It is used to reason and to justify the traffic safety plan of Flanders. The target is to reach zero fatalities and seriously injured by 2050. In the figure below (FIGURE 1: Vision Zero Goals Flanders (Adapted from Flemish Department of Mobility and Public Works, 2021), the target numbers by a specified time period are given. The goal is to reduce the numbers by 25% by 2025 and by 50% by 2030 (WHO, n.d.). The maximum number of fatalities and people injured is set. To reach these goals priority points for attention and 37 countermeasures are developed.

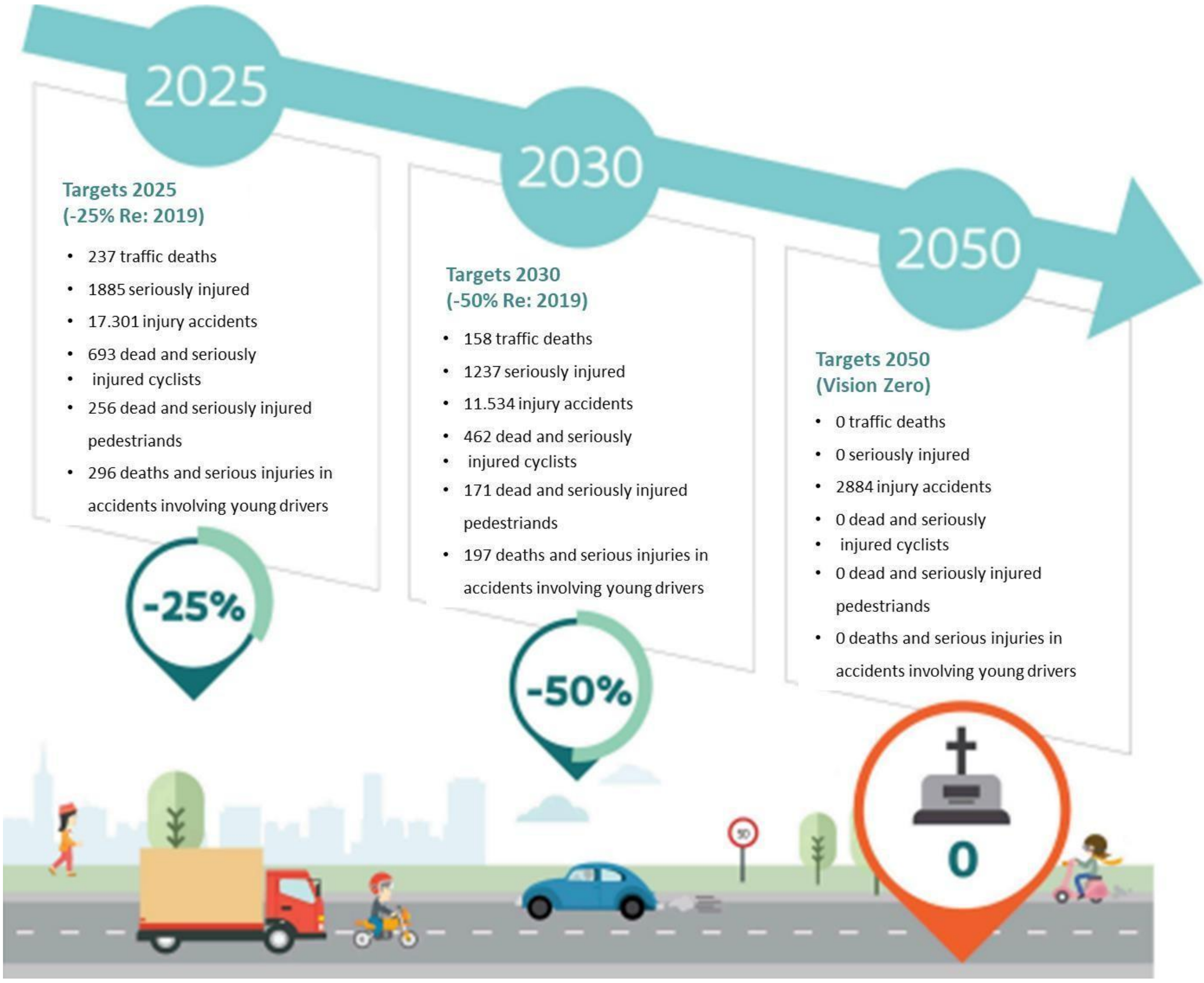


FIGURE 1: Vision Zero Goals Flanders (Adapted from Flemish Department of Mobility and Public Works, 2021)

Lydia Peeters (2021), minister of Mobility stated: "vision zero remains the ultimate goal …, different viewpoints are used to identify the traffic safety problems… and the active road users (pedestrians and cyclists) are the main focal point during this development". The minister wants to tackle the issue by using MIA, which translates to approaching mobility in an innovative manner. The key terms are reaching the goals fast, together while being alert. It means effective procedures, good cooperation on multiple levels, and flexibility when situations develop. It tends to lean towards the safe system approach, later more on that matter. According to Peeters (2021), traffic safety is reached by making the infrastructure safe and comfortable. The so-called black spots need to be tracked and solved actively and this by means of a proactive and innovative manner. Proactive means, taking action before any kind of crash occurs. It is the first element for introducing the topic of this paper.

Peeters (2021) already mentioned this, but All for Zero (2021) had the same conclusion on this matter. Higher traffic safety is achieved by different factors such as road infrastructure, speed limits, safe vehicles, traffic education and safe behaviour (All for Zero, 2021). New challenges are also rising: larger – heavier vehicles, more autonomous vehicles, driving under the influence of drugs, new transport modes (e-bikes, steps, …), new types of distractions and more traffic on the roads. All the elements above, interact with each other. Making a trip is getting more and more complex. Therefore, the STOP principle can be used to prioritize the formulation of objectives, plan the mobility policy, decide on resources, and develop and apply new technologies in the order of S (pedestrians), T (cycling and micromobility), O (public transport and shared rides), and P (private cars and planes), according to Netwerk Duurzame Mobiliteit (2020). The prioritisation is directed towards to most desirable mode of transport. According to Passmore (2023), humans make mistakes but it should not result in death or severe injuries. That is why the safe system approach proceeds from the mindset that crashes can be prevented and road safety is a shared responsibility. Road injury prevention policy is shared by governments, media, professionals, NGOs (non-profit organisations), police, industry and users. If one part of the system fails the other parts provide protection to prevent or reduce injuries.

Transport is complex; new challenges are occurring and according to the vision of the safe system approach: humans can't be blamed for mistakes. It introduces a second important element to the goal of this research. It is interesting to know which interactions between certain transport modes will likely result in a crash. The figure below (FIGURE 2: Collision Matrix traffic deaths with their opponent in fatal crashes (All for Zero, 2021)) shows that most fatalities are due to unilateral crashes with the car. When several road users are involved, it is between cars - and motorcycles, - cars, - bicycles and at last cars and pedestrians. (All for Zero, 2021)

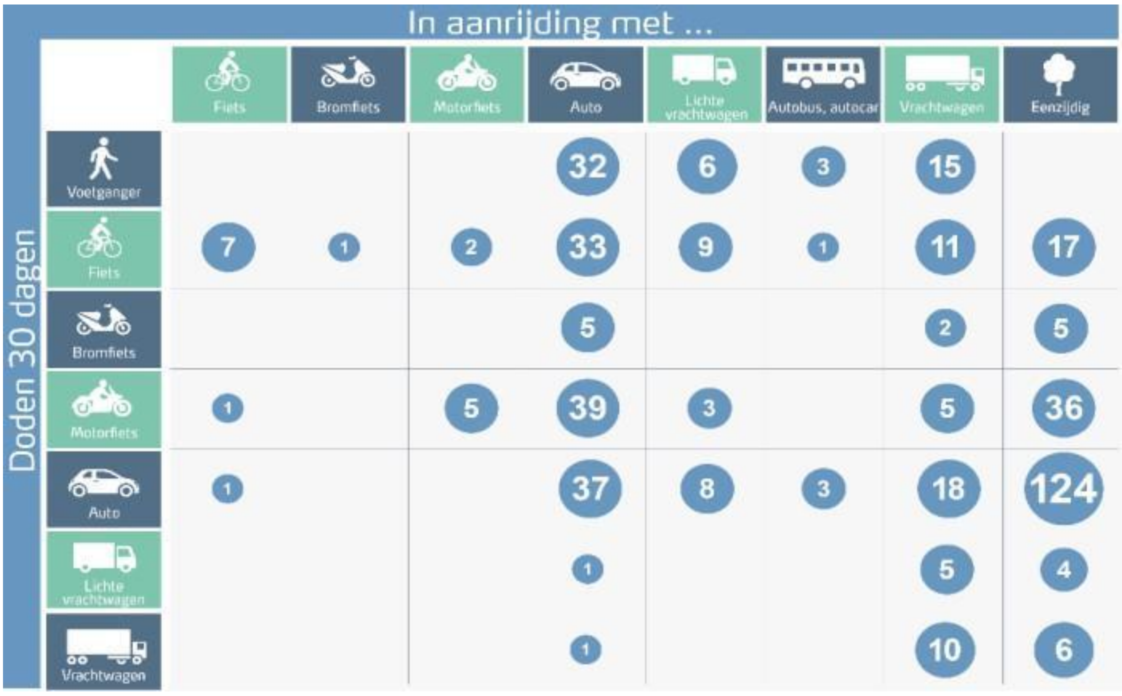


FIGURE 2: Collision Matrix traffic deaths with their opponent in fatal crashes (All for Zero, 2021)

Crashes with severe and light injuries certainly deserve that much attention. The majority of the crashes happen on Flemish regional and municipal roads, a combined 92% (Statbel cited in Statistics Flanders, 2023). More kilometres are driven on the highways, nevertheless, 8% of the crashes occur there. Statbel cited in Slootmans (2022) confirms this inference; most crashes occur on roads where a maximum speed of 50km/h or 70km/h is allowed. It provides input for investigating these types of crashes on the above-mentioned types of roads.

Vision Zero finds its roots in the safe system approach. Safe and well-maintained infrastructure is one of the key pillars; to guarantee this; research, evaluation and monitoring are crucial (All for Zero, 2021). The measures taken include forgiving bike infrastructure, safe pedestrian crossing, safe school – residential – and work routes, … . It is considered the third important element for introducing the topic. Vision Zero, the safe system approach, STOP principle, and MIA form the basis of this research, upon which further work will be built.

1.2. Drone research within Vision Zero and safe system approach

As has already been mentioned before, Peeters (2021) focuses on an innovative mobility approach. Infrastructure and driving behaviour must be studied in a proactive manner. The minister suggests, for example, the use of drone technology. It fits well to identify dangerous intersections and make them safe effectively. At the moment of writing, 2023-2024, dangerous intersections or infrastructure, in general, are evaluated by the number of crashes and the severity of the injuries. However, Peeters (2021) wants to prevent crashes from happening. The drone technology must provide insight into the (potentially dangerous) interaction between different transport modes and the environment (infrastructure). It is the intention to come up with a new method and develop an innovative way to (proactively) research and evaluate infrastructure. As part of the MIA project, research has already been conducted in collaboration with IMOB (the UHasselt Institute for Mobility). According to Brijs (2023), cited in IMOB (2023), "... drones can be used to analyse specific traffic situations … recommendations and possible solutions are then provided based on the analysis of the drone images and are used by AWV (Agency of Roads and Traffic in Belgium). According to Brijs (2023), cited in IMOB (2023), "this technology is a simple, efficient, and cost-effective way to gain a quick understanding of the entire traffic situation".

Drones are becoming increasingly popular to improve safety, reduce congestion, monitor roads, detect and report crashes (Frackiewicz, 2023). They are efficient and cost-effective. Hazards that could be dangerous for road users can also be identified by drones. In some countries, they are also used for enforcement, such as red light negation or speeding. The drone's purpose in this research is to collect data about traffic patterns and other factors to identify dangerous patterns of interaction between road users at intersections or other infrastructure. According to Frackiewicz (2023), regulations and guidelines are necessary though to use drones responsibly and efficiently, more of that is under the chapter Legislation of drones.

Rolink (n.d.) states that with drones, it is possible to accurately identify traffic patterns by recording every movement in great detail. This confirms the findings of Brijs (2023) and Frackiewicz (2023) on the advantages of drone research. The tool is cost-efficient and provides detailed data on traffic patterns, speed, and gap time. It allows for reliable and detailed research without being influenced by traffic behaviour, such as the Hawthorne effect; e.g. people adjust their behaviour when being observed (Mahtani & Spencer, 2017). Additionally, it can improve safety and serve as a means of communication between organizations, citizens, and politicians.

With Vision Zero, which is based on the safe system approach, researchers are stimulated to use innovative ways to increase safety on the roads for all transport modes. Vision Zero considers it important to provide safe infrastructure for cyclists and pedestrians. Hence, those interactions will be looked at as well. Therefore, innovative drone technology will be used to conduct this research.

Drone research is a versatile form of research with multiple applications. It is known to be used for connected and autonomous vehicle applications, traffic efficiency research and traffic safety research (Fu et al., 2023). According to Outay et al. (2020), other major transportation domains where UAVs can be applicable are traffic monitoring and highway infrastructure management. Examples of drone research for traffic safety include accident investigation and risk assessment, more specific on the identification of potential conflicts and risky lane changes manoeuvres (Outay et al., 2020). This research focuses on traffic safety, specifically identifying potential conflicts during square green cycles. More information on this topic can be found in the Problem statement chapter. It shows the amount of potential this rather new form of investigation has.

1.3. Problem statement

1.3.1. Statistical numbers on crashes

In 2022, there was a decrease in the number of fatalities on Belgian roads, with 510 lives lost compared to the previous year of 2019 (Statbel, 2023). Additionally, there was a reduction in the number of severely injured individuals, with 3100 reported. However, there was an increase in lightly injured road users, with 34.033 incidents recorded when compared to 2019. In 2019, Belgium had a total of 37.719 road accidents (Statbel, 2022). This figure decreased slightly to 37.643 in 2022 (Statbel, 2023). Despite a decreasing trend overall, the number of cyclist fatalities has increased by 7,4%, surpassing 100 fatalities. Information regarding 2020-2021 is not comprehensive due to the COVID-19 pandemic. According to Ethias (2019), 23% of the crashes occur when making a manoeuvre (right turn, left turn, crossings, merging lanes, …). The most deadly situations are side collisions (25%) and crashes where pedestrians are involved (13,7%). 54% Of the total crashes occur inside city limits. In Belgium 81,3% of the victims comprise pedestrians or drivers. The number of vehicles that drive in Belgium has increased (Statbel, 2022). Electric and hybrid cars show the biggest increase, respectively
+75,4% and 44,9%. <u>Peeters (2021) already mentioned that new transport modes such as e-bikes and steps are becoming increasingly popular</u>. According to Car-pass, which has a correct overview of the driven kilometres, the amount is still rising but the Belgian population is not yet at the peak as before Covid – 19.

With more road traffic, more trips, and transport modes becoming more complex, a safe environment is not yet reached. Moreover, under-registration of traffic crashes makes it hard to correctly overview traffic safety challenges (Macharis et al., 2011). They quote: "mistakes such as … inaccuracies, errors and timely availability of crash data, availability of data, completeness, correctness, accuracy, consistency and the up-to-dateness of the crash statistics." The numbers aren't good and the correct representation of reality is unavailable.

Hence the data that is provided doesn't represent reality. The available numbers are crashes that did occur. Astarita & Giofré (2018) stated that potential crashes are not considered when evaluating traffic safety. Hyden, cited in Astarita & Giofré (2018), developed in 1977 the Hyden pyramid. It shows that crashes and injuries are just the tip of the iceberg and the smallest part of the total number of conflicts. <u>Much more near-misses, slight and potential conflicts happen in reality.</u> Those types also indicate infrastructure safety and should be considered when evaluating them. The road manager and governments should not wait for hospital data and reconstruct infrastructure after 5 years of using the road network.

1.3.2. Proactive and reactive approach

Two approaches are used to evaluate road safety. A first method is the reactive approach. When problems occur, they get screened, diagnosed and cured (countermeasures are implemented), according to the United States Department of Transportation (n.d.). In Belgium, these dangerous locations are now decided by the following procedure. Agentschap Wegen en Verkeer (Agency of Roads and Traffic in Belgium – AWV) uses the 531-score method. If a crash occurs 1 point is given for slight injuries, 3 points for high severity and 5 points for a fatality (AWV, 2022). When vulnerable road users (VRUs) are involved, an increasing factor is applied. To be added to the list of black spots, a score of at least 15 must be reached based on crash data from the last three years, according to AWV (2022). This means that three years of crashes must occur before any action is taken. A proactive approach also exists. <u>Safety problems need to be prevented and dealt with before they even manifest themselves</u>. Both the approaches should be used, and not one of them excludes the other. Two main advantages of the proactive approach are: (A) a crash does not need to happen before countermeasures are developed and implemented (B) it has a relatively lower cost to research the infrastructure than to repair the damage of the infrastructure and physical suffering. The community cost of traffic crashes in Belgium is estimated at €13 billion (VIAS, z.d.). That is 2.9% of the GDP, including severe, slightly injured, and material damage.

1.3.3. Green traffic light cycle as a new concept

Besides investigating an infrastructural intervention, a look will be taken as well at "vierkant groen" translated to square green or green traffic light cycle. It is a concept that is increasingly being implemented on the roads of Flanders, Belgium (AWV, n.d.). One of the measurements that is suggested by Peeters (2021) is conflict-free and smart-controlled traffic lights. The concept of square green is in line with this countermeasure. There should be sufficient time allotted for crossing, ensuring smooth traffic flow and avoiding red light negation. Following the proactive approach, conducting a comprehensive drone investigation can provide valuable new insights. Active road users receive a green signal simultaneously and can traverse the junction in varied directions at the same time (AWV, n.d.). The goal is to divide motorised traffic and avoid possible blind spot accidents. A pedestrian still has to use the pedestrian crossing but is able to cross and turn left/right in one go (o2o, n.d.). A cyclist is permitted to cross the junction at a diagonal angle but must yield to pedestrians and any other cyclists approaching from the right (like motorised vehicles do at an intersection). The green traffic light cycle gives a new way of interacting with active road users. Not a lot of information is known about this quite new concept.

After some careful consideration, it becomes apparent that new issues emerge in tandem with a new concept. As has already been mentioned by Peeters (2021), e- bikes and steps are becoming more popular as well as an increased focus on active road users. Ethias (2019) mentioned the dangerous manoeuvres, collisions and the involvement of active road users, see chapter Statistical numbers on crashes. How are they interacting with each other on a square green intersection? How do the right turning manoeuvres (typical blind spot cases) look like with this concept, are collisions still severe or are new types of conflicts occurring between the active road users? Several cities have already investigated the implementation of green squares. According to Watteeuw (2023), the introduction of a green traffic light cycle in Gent, Belgium resulted in an increased feeling of safety for 62% of pedestrians and 75% of cyclists. Square green might be subjectively safe but research must prove that objective safety is also increasing. The waiting time for pedestrians and cyclists remained the same as before the intervention, while motorised traffic experienced an average increase in waiting time of 30 seconds. The STOP principle prioritises vulnerable road users over motorised traffic (Netwerk Duurzame Mobiliteit, 2020). According to Gordts (2023), the implementation of square green at an intersection in Antwerp, Belgium, has caused chaos when vulnerable road users are not familiar with it. This section suggests that additional research is required for the safe development and widespread implementation of this concept on the roads. Considering the incentive of proactive and innovative research where drones have high potential, the transition is made to the purpose of this research.

1.4. Summary

Traffic keeps getting more complex and the number of trips keeps on rising. Moreover, only a small part indicates the problem. Potential crashes, near-collisions and slight conflicts also need to be taken into account. The community costs of a traffic crash are a relatively big part of a country's GDP. Dangerous locations are now (2023-2024) decided by the following procedure. Agentschap Wegen en Verkeer (Agency of Roads and Traffic in Belgium – AWV) uses the 531- score method. If a crash occurs 1 point is given for slight injuries, 3 points for high severity and 5 points for a fatality (AWV, 2022). It means three years of crashes must pass before any action is taken. It suggests for research, wherein the proactive approach is more developed. More insight information, monitoring and a bigger picture of the real traffic safety problems is necessary to reach the vision zero goals of 2050. As was already mentioned, drones are an innovative way to investigate this matter and to provide concrete solutions to the dangerous infrastructure, the so-called black spots.

With new concepts like the green traffic light cycle new issues develop, for example interactions between active road users themselves. Keeping the proactive approach in mind, these are also necessary to investigate. The process can be handled more efficiently with drone technology and proximal safety indicators. It emphasises the need for a comprehensive drone investigation to gain insights into the interactions of active road users at intersections.

2. Research objectives and questions

There are more interactions between all kinds of road users. Nevertheless, traffic should be safe for all. With Vision Zero, the safe system approach, the STOP principle and MIA in mind, the main purpose of this research is to develop the proactive approach further and to make the environment (infrastructure) safer and more liveable. This means acting in prevention, not waiting for injuries or fatalities to happen and then solving the problem.

The goal is to set up a before – and after study, to evaluate an infrastructural implementation aimed at improving road safety at a location. An intervention is normally evaluated after a usage of 3 - 5 years. After this period, it is concluded whether the infrastructure is safe or not. With a proactive method, a study can be performed to investigate the safety after just completing the construction. The same thought is behind the evaluation of the green traffic light cycle. It is a fairly new concept and insufficient data is available regarding particular interactions or the potential emergence of novel types of conflict. Dangerous manoeuvres, collisions between active road users involved at the intersection during a square green is just one of the examples. Subjective safety increases but the level of objective traffic safety is also important to investigate.

The previous paragraph highlights the need for further research to ensure the safe development and introduction of this concept on the roads. The potential of drones is high, so it is important that it is used for proactive and innovative research. Their footage will be used to examine the measures taken in specific surroundings. This way the road manager can be provided with reliable and validated data about the effectiveness of an infrastructural implementation.

With the problem statement that is provided and the goals that are set – up, the research questions for this paper can be written. The main question in this thesis sounds like this:

What is the effect of the infrastructural intervention of a green traffic light cycle, with the aim of improving road safety for road users following the STOP principle, based on drone technology and its proximal factors?

To answer the formulated question above, the following sub-questions have been defined.

- Which proximal factors are necessary to reason the drone–based evaluation?
- Which suggestions can be given to make the infrastructure safer, based on the conflict results?

- Which conflicts occur on a green traffic light cycle at location R70 Kolonel Dusartplein & N702 Koning Boudewijnlaan in Hasselt?
- What is the seriousness, including severity and probability, of these conflicts on site R70 Kolonel Dusartplein & N702 Koning Boudewijnlaan?

- Which conflicts occur on a green traffic light cycle at location R70 Guffenslaan & Kunstlaan in Hasselt? What is the seriousness, including severity and probability, of these conflicts on site R70 Guffenslaan & Kunstlaan?

- Which conflicts occur on a green traffic light cycle at location R70 Leopoldplein; N20 Luikersteenweg; N80 Sint-Truidersteenweg?
- What is the seriousness, including severity and probability, of these conflicts on site R70 Leopoldplein; N20 Luikersteenweg; N80 Sint-Truidersteenweg?

3. Literature review

3.1. What is considered as road safety

The research questions, as established in the chapter Research objectives and questions, contain a few key words. The purpose is to define these key elements to fully understand the meaning of the question and provide a comprehensive answer. According to the United Nations, as cited in Wegman (2017), road safety is a matter of public health and must be included in sustainable development goals for the future. Health is considered the highest priority and goal that can be achieved. Road safety can be viewed from a health perspective. According to Pan American Health Organization – PAHO (2010), "road safety pertains to the measures taken to reduce the risk of road traffic injuries and death … improve the road safety legislation and create a safer, more accessible, and sustainable environment for transport systems as well as for all road users". This definition contains a few interesting elements worth diving into. "Reducing the risk of injuries and death"; this follows the idea of the Vision Zero concept, mentioned in the Vision Zero and safe system approach chapter. Humans are allowed to make mistakes but they shouldn't result in severe injuries or death (Passmore (2023). "Create a safer, accessible and sustainable environment for all road users", it is in line with the STOP-principle that prioritizes vulnerable road users in the design and decision making (Netwerk Duurzame Mobiliteit, 2020).

The future of road safety varies across the world (Wegman, 2016). Countries with well-established road safety measures are moving towards proactive approaches, such as the use of drone technology for investigation purposes. This approach is relatively inexpensive, as discussed in the Examples of traffic safety research with drones chapter, and can also be implemented in less developed countries.

3.2. What is considered as a traffic conflict

Perkens and Harris (1967), cited in Chin & Quek (1997), mention that conflicts were based on evasive actions and readily observable such as brake lights, sudden changes of lanes, … . According to Older and Spicer (1976), Glauz and Migletz (1980), Garder (1989), cited in Chin & Quek (1997); drivers failed to take action and accidents and near missed arise. Therefore, this definition proves that even without these evasive actions critical situations still exist. According to Pearl (2009), cited in Tarko (2021), detecting traffic encounters and conflicts is related to the critical task of separating aggressive behaviours and unclear manoeuvres. Amundsen and Hyden, cited in Chin & Quek (1997), give an unified definition of traffic conflicts: "it is an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remained unchanged". A remark on this definition is that the level of risk is undefined and so speculations still exists.

The figure below (FIGURE 3: Pyramid of Hyden representation of traffic encounters (Chin & Quek, 1997)) shows the pyramid of Hyden, which represents traffic encounters. For this research, it is important to focus on the upper part of the pyramid, which includes potential, slight, and near conflicts. The tip of the pyramid represents actual accidents resulting in damage and injuries. In this drone research, it is crucial to proactively examine potential to near accidents.

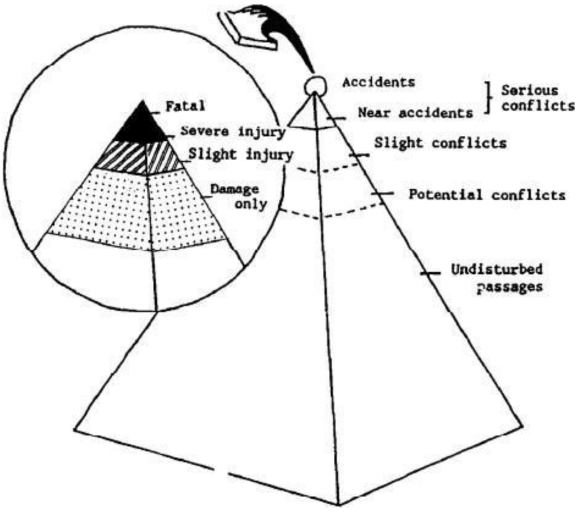


FIGURE 3: Pyramid of Hyden representation of traffic encounters (Chin & Quek, 1997)

3.3. Research on green traffic light cycles

Now that road safety and traffic conflicts are defined, it is necessary to take a more detailed look at green traffic light cycles. In the literature other terminology is used as well such as: pedestrian phase, exclusive pedestrian phase, cycling phase, pedestrian scramble, intersection scramble, diagonal crossing scramble intersection, All-way walk, Scramble crossing and Barnes dance.

3.4. Adapting large intersections with green traffic light cycles

Holzem et al. (2015) researched the implementation of diagonal cross, median cross, two-stage Barnes Dance, and midblock cross on a superstreet intersection. These intersections are considered large crossings. A superstreet is a divided highway with intersections that do not allow minor cross-street traffic to go straight through or turn left. This change reduces the number of traffic signal phases and allows longer green lights. The suggestions provided by Holzem et al. (2015) are variants of the green traffic light cycle. Regarding pedestrian crossing configurations, a two-stage Barnes Dance is suggested, which involves a full green traffic light cycle or diagonal crossing. The research found that the direct cross over the intersection was the recommended configuration for bicycle crossings due to its lower average stopped delay, total stop, and travel time per route compared to the U-turn configuration. It is important to note that the study did not investigate potential conflicts between vulnerable road users, which is a limitation.

3.4.1. Suggestions based on type of road user and location characteristics

Chen et al. (2014) suggest that trade-offs between pedestrian and motorist safety at intersections are possible. The study identifies four countermeasures (types of green traffic light cycles) for an urban intersection that yield varying safety outcomes for different road users. The first method is to increase the total cycle length, which means increasing the duration of one complete traffic signal phase. The second method is the Barnes Dance, which stops all motorised traffic and allows vulnerable road users (VRUs) to cross in all directions (including diagonal) at the same time (Chen et al., 2014). The third method is split phase timing, which splits the green time into multiple phases to prioritise certain movements at intersections (Chen et al., 2014). The last method is signal installation, which is the standard light cycle phase. While total cycle length and Barnes Dance improve the safety of vulnerable road users, they are less effective in reducing motor vehicle crashes due to increased waiting times and potential pileups (Chen et al., 2014). Split phase timing and signal installation are more effective in directly separating traffic and reducing possible conflicts. The selection of a green traffic light cycle variant should be based on the specific characteristics of the location in question. For downtown areas with high pedestrian traffic, Barnes Dance (green traffic light cycle) is more appropriate, while split phase is more recommended for narrow streets and the need for quick crossings. Increasing the total cycle length is considered appropriate for elderly pedestrians but may not be necessary in school areas.

Zhang et al. (2015) recommend that the use of exclusive pedestrian crossing should be applied in locations with high traffic speeds, long crossing distances and low pedestrian volumes. Intersections with low traffic speeds, short crossing distances and high pedestrian volumes are less ideal for this type of countermeasure. Moreover, the crash rate and crash severity decreases with a higher pedestrian exposure. According to Zhang et al. (2015), it is crucial to enforce crossing rules to decrease jaywalking and so maximize safety also on exclusive pedestrian crossings.

3.4.2. Advantages of green traffic light cycles

Beauregarde, Thomas, Barbour, Redshaw, and Bunting, cited in Postmedia Network Inc. (2018), mention that scramble crossings (green traffic light cycle) are not necessarily an innovative development. Cities such as Auckland have demonstrated the efficacy of the concept in terms of safety since the 1950s. It is a simple and cost-effective solutions which requires minimal resources. The safety issues on intersections are clear and can be addressed promptly and effectively with the scramble crossing countermeasure. Lumley (2023) indicates that the benefits of scrambled

pedestrian crossings (green light cycles) are a reduction in harm to pedestrians, a smoother traffic flow for motorised traffic, and a reduction in pollution due to the smoother traffic flow. This countermeasure is getting increased popularity in Australia and New Zealand. Lumley (2023) mentioned there is a willingness to pay towards the transition off scramble crosswalks and so emphasize pedestrian safety. Although mentioned previously as a cost-effective countermeasure, it is important to note that public willingness to invest should also be considered. Kinney (2016) and Mena Report (2019) confirm the above-mentioned conclusions by advising that Barnes Dance crossings are valuable for implementation in New York City and New Zealand as they provide a safe way to cross an intersection.

3.4.3. Externalities of green traffic light cycles

Disadvantages are also noticeable during green traffic light cycles. According to Giles (2016), the scramble light crossing still causes chaos at the intersection and redirects traffic towards side streets. As is the case with standard traffic light phases, scramble light crossings frequently encounter issues with pedestrians who cross the road while motorised traffic has a green light. Giles (2016) suggests that police patrols should be conducted if this occurrence does not change. Herms (1972) does not necessarily suggest police patrols, but recommends raising awareness through an education program. Herms (1972) suggests that unsafe use of intersections is caused by pedestrians' attitudes and lack of caution.

An often occurring concerne about exclusive pedestrian phases (diagonal crossing or green traffic light cycle) is the time los for motorized traffic. According to Vytautas et al. (2023), the time losses are mostly beneficial on intersections with following conditions: 2+2 lane streets, more than 900 pedestrians/hour and more than 1600 vehicles per hour. Although the lost time is less, according to Zhang et al., are low pedestrians volumes more beneficial for the safety aspect. Smaller intersections can also be considered for this countermeasure but the volume of vehicles per hour have to be medium (Vytautas, 2023). The amount of pedestrians is less important in that situation. Wang et al. (2021) indicated that higher pedestrian flow, with constant vehicle flow, enhances the effectiveness of exclusive pedestrian phases (EPP).

3.4.4. The role of orientation level and pedestrian density

Stock and da Silva (2023) identified two key factors that affect crossing times and congestion patterns at scramble intersections in urban environments: orientation level and pedestrian density. Flexibility and the amount of pedestrians facilitate a smooth crossing at these complex scramble intersections (green traffic light cycle). Examining the two key factors in more detail, the chevron effect can occur when unidirectional flows of pedestrians or vehicles segregate into diagonal stripes (orientate themselves), forming a chevron pattern (Cividini, 2013). This provides insight into how particles, or road users, behave in parallel lanes. If the concentration of pedestrians is higher, they orientate themselves more easily (Stock and da Silva, 2023), a chevron pattern is than more likely to occur (Cividini, 2013).

3.4.5. Safety impacts of green traffic light cycle

Ghaneei (2023) found that implementing a scramble phase at three different intersections resulted in a significant reduction of severe conflicts by 50%-60% over a one-month period. Additionally, right-turn-on-red violations decreased between 28.5% and 34.5%. However, the limited safety indicators and short-term evaluations suggest the need for further research. It is worth noting that Gårder (1989) reached a similar conclusion to Ghaneei (2023). Exclusive pedestrian signal phases (scrambles) were tested at three sites and revealed significant safety benefits in a small town. However, they lacked effectiveness in Stockholm due to a high rate of red light-walkers. According to Gårder (1989), town size and traffic volumes are key factors influencing this frequency. Ismail et al. (2010) found that the implementation of a pedestrian scramble phase (green traffic light cycle) has a positive impact on intersection safety. A comparison of a before-and-after study revealed a reduction in conflict frequency and spatial density of conflicts. According to Allyson et al. (2004), implementing a pedestrian scramble signal resulted in a reduction of pedestrian-vehicle conflicts, but an increase in pedestrian-pedestrian violations due to the increased proportion of pedestrians crossing the safe side crosswalk (it is the crosswalk parallel to the flow of vehicular traffic) illegally. Overall, Allyson et al. (2004) concluded that safety had improved effectively.

A study from intersections in Canada has shown that there is an increase in pedestrian violations after the implementation of pedestrian scramble operation (green traffic light cycle)(Kattan et al., 2009). The study found a 13% increase in pedestrian violations for safe-side crossings (parallel to the flow of vehicular traffic) and a 2% increase in pedestrian violations for unsafe-side crossings (perpendicular to the vehicular traffic flow), as reported by Kattan et al. (2009). Ongoing monitoring is recommended by researchers as a conclusion drawn from multiple studies.

Juozevičiūtė and Vytautas (2022) reached the same conclusion. A decrease was found in pedestrian-vehicle conflicts and an increase in pedestrian-pedestrian violations. The study also investigated the difference between exclusive pedestrian crossing with and without diagonal crossing. The results showed a 66% reduction in conflicts with diagonal crossing, compared to a 100% reduction without diagonal crossing. It is worth noting that the latter number warrants further investigation. A 100% decrease was observed at an intersection with zero accidents before the implementation and zero accidents after the implemenation. It means that the exclusive pedestrian crossing without diagonal crossing is definitely not a harmful countermeasure, but it would be more interesting to see the results of this implementation on a intersection where accidents do occur in the before analyses. The table presents the advantages and disadvantages of an exclusive pedestrian phase with a diagonal crossing (Juozevičiūtė & Vytautas, 2022).

TABLE 1: Advantages and disadvantages green traffic light cycle (Juozevičiūtė & Vytautas, 2022)

	Pedestrians	Vehicle drivers
Advantages	- Reduced number of pedestrian conflicts by 66% - Priority for pedestrians at intersections - Move to pedestrian friendly cities (STOP-principle) - Shorter walking distance by 5%-13%	- With appropriate light cycle delays can be minimized - No obstacles on intersection so vehicles can move freely
Disadvantages	- Increased number of pedestrian-pedestrian violations by 21%-20% - Problems for visually impaired or blind persons	- Installation of junction could increase vehicle delays

3.5. Legislation of drones

Because drone usage is crucial for the data collection in this research, information is provided about the legislation and some (dis)advantages.

From 2021 onwards, Belgium has taken over Europe's drone legislation. There are a few uniform fundamentals that should be considered by everyone and so for this specific research. The higher the risk, the stricter the legislation. Three main categories are stated which are open, specific and certified. Belgium has translated the mandatory laws to the following demands (Lemmens, 2020):

- Unmanned aircraft system (UAS) operators must register with the Directorate-General for Aviation of the Federal Public Service Finance (FOD) Mobility and Transport.
- For the specific category in which the data collector will be operating a minimum age of 16 years old is required.
- Every flight that is executed is in accordance with Regulation 2019/947.
- Insurance is mandatory for every operator. (Lemmens, 2020)

A concern about working and analysing drone footage is that the unmanned aerial vehicle (UAV) is not exactly at the same location during all the recordings (Al Sobky et al., 2023). This results in slight differences in the data. Al Sobky et al (2023) give examples as “distortion, occlusion, change in illumination and blurring”. Vertical translations result in scaling deformation and horizontal translations cause shifting deformations. While rotational movements around the (non -) vertical axis have the issue of providing tilting deformation. An error parameter is included in the calculations to treat the mistakes in the data.

The drone technology seems very promising for this research, but there are also some disadvantages. The first, significant problem with drones is the difficulties with privacy laws. Padilla (2022) distinguishes three privacy issues the UAS has to contend with.

Physical privacy is the person's personal space which is entered. A drone can easily capture this material with high-resolution and detailed footage. (Padilla, 2022)

Location privacy has to do with recording properties. From a certain altitude, drones can film and take pictures of land usage. The number of buildings and size of constructions on a certain land that may be private can be interesting data for people with wrong intentions. (Padilla, 2022)

Lastly behaviour privacy which can be infringed. If people notice being recorded, the person that is researched can alter their behaviour. For this research it is important that normal behaviour is performed, the person acts naturally and is not being extra cautious or extremely dangerous. (Padilla, 2022)

The European law prohibits drones from flying anywhere. It is for privacy reasons but also for the safety of the operator, environment and the community. It can be that radio waves, wildlife or electricity pylons interfere with the drone's signal and that can cause dangerous situations. (Padilla, 2022)

It is stated that using UAV to evaluate the transport network is cost-effective. This is the case compared to the standard old methods, but Frackiewicz (2023) writes that purchasing, operating and the software to operate them and analyse the data is not cheap. This remark should be considered when performing research based on drone technology.

3.6. Examples of traffic safety research with drones

As briefly discussed in the introduction, new concepts raise new questions and insights. In Ghent, a square green traffic cycle made pedestrians and cyclists feel (subjectively) safer, 62% and 75% respectively (Watteeuw, 2023). Additionally, a drone was employed to analyse the traffic situation at the same location, which was deemed crucial for making necessary adjustments, according to AWV, as cited in Van Den Hoof (2023). It was found that the intersection was not operating optimally. Difficulties arose with the priority rules for vulnerable road users and the congestion for motorised traffic. Gordts (2023) reached the same conclusion in Antwerp, where chaos was experienced by vulnerable road users who were not familiar with the concept of square green. Kiekens, cited in Van Den Hoof (2023), stated that drone research has potential. Kiekens (2023) quotes: "The drones replace traditional measuring loops, light cameras and manual counting. Their use has advantages, such as faster results, but also disadvantages, such as short recording time and being undeployable in bad weather. Their role is mainly supportive; human inspections also remain necessary", according to Kiekens, cited in Van Den Hoof (2023).

Drones were also used in the province of Limburg, Belgium to investigate three locations. According to Brijs, cited in MOW (Mobiliteit en Openbare Werken - Mobility and Public Works, 2023), this type of research provides a fast, accurate, and comprehensive understanding of the traffic situation. The subsequent measurements can be small in scale, making them quick and cost-effective to implement.

Equinox's Drones (2023) confirms Brijs' (2023) findings that using drones for research is a cost-saving technology due to its high precision, flexibility for quick inspections, and provision of in-depth and detailed data. According to Equinox's Drones (2023), drones are more economical to buy, sustain, and fuel than other, bigger, and heavier equipment. Additionally, the built-in GPS makes it relatively easy to guide them to a specific location for data collection. The drone is easy to deploy and can operate at different altitudes for various inspections. Jiao and Fei (2023) conducted tests at different altitudes to determine the optimal balance between an overhead view and detail. They tested three heights: 40m, 60m, and 80m. The results showed that a height of 40m provided the highest level of detail while still maintaining a good overview, as the height of the surrounding buildings did not exceed 40m. Equinox's Drones (2023) states that additionally, the images are high-resolution, providing detailed recorded information. However, the research revealed some disadvantages, including privacy violations and manipulation. Additionally, the uncertainty of legislation surrounding drone usage remains, as laws are still evolving. Furthermore, the use of drones is heavily dependent on weather conditions, which can affect data collection and potentially endanger the safety of surrounding citizens, as noted by Equinox's drones (2023).

According to the study of Dohyung (2020), cited in Cardito & Vanderheyden (2023), it is possible to analyse not only the quantity of active road users, but also their characteristics and behaviour, including gender. Using drones as an observation technique shows potential as it covers a large research area without requiring many instruments. It enables the observation of complex movements of road users, rather than just counting them. Dohyung (2020) encountered a notable limitation during the investigation, which was the restricted duration available for data collection. This was attributed to the limited battery capacity of the employed drone.

3.7. Proximal indicators

To decide if an infrastructural intervention is safe, the data that is obtained has to get meaning. Proximal safety indicators are there to reason the data and prove conclusions in a scientific way. There are a lot of indicators in the literature, but the relevant ones for drone technology are selected. A second remark is that each indicator has some limitations, advantages and is unsuitable for every collision type. It can be that specific infrastructural intervention has characteristics that don't comply with the characteristics of the indicator.

3.7.1. Temporal & spatial indicators

A first category is the temporal and or spatial proximity indicators; they assume the closer a vehicle is to another one the greater the chance of a collision (Ferreira et al., 2017).

Time-to-collision (TTC) is defined by Al Sobky et al. (2023) as "projected time until two interacted road users would collide if they continued on their collision course with unchanged speeds and directions. The table below (TABLE *2*: Overview temporal and spatial indicators (Ferreira et al., 2017)) shows an overview of the advantages, limitations and suitability of this indicator. The relevance of the TTC indicator lies in its suitability for crossings and investigating pedestrians in traffic who are highly involved in square green traffic cycles (Ferreira et al., 2017). Additionally, it provides more information than the Post-encroachment time indicator. However, a disadvantage of this indicator is that it does not indicate the severity of a crash if one occurs.

Post-encroachment time (PET) is the "elapsed time between the departure of an encroaching vehicle and the arrival of a trailing vehicle at the same point" according to Al Sobky et al. (2023). There is a correlation between the PET value and a crash. When the PET value decreases the correlation factor of a crash increases. Although the previous paragraph stated that TTC provides more information than PET, this indicator will also be used as it produces other valuable insights. According to Ferreira et al. (2017), PET is particularly suitable for researching intersecting conflicts, crossings, and pedestrians, which is relevant for square green research. However, a limitation of this indicator is also a strength in this research, considering the investigation area. PET is only useful in transversal trajectories that can occur during square green traffic cycles for vulnerable road users.

To determine whether a collision occurred, or if the interaction was safe, a threshold value is required. Different values for the TTC indicator have been proposed by various sources. Das & Maurya (2020) suggest a critical value of 3 seconds for lane-based traffic, but this varies for non-lane-based traffic. Since interactions on a square green intersection are not necessarily lane-based, other values must be considered. Bottu (2021), as cited in Cardito & Vanderheyden (2023), proposes a threshold value of between 2s-0s for TTC.

A time of 2s is considered safe, and 0s is registered as an accident. Using these values eliminates an unnecessary high amount of accidents that would occur if a value of 3s were used. Yang et al. (2021), give a extra seperation in the threshold values. A TTC time of 0 < TTC < 1.0s results in a serious conflict; 1.0s < TTC < 1.9s means a general conflict and a TTC of > 1.9s does not constitute a conflict. These values can also be applied to non-lane-based traffic. Van Der Horst (1990), Sayed et al. (2013), Hogema & Janssen (1996), Vogel (2003), Meng & Qu (2012), Huang et al (2013), Farah et al (2008) and Hegeman (2008), cited in Ferreira et al. (2017), state that the critical or threshold value required depends on the specific condition being investigated. These conditions may include approaches at an intersection, low or high level conflicts, signalized intersections, and urban road tunnels. The cycle of a green traffic light at a square intersection is determined by the approach conditions and the level of conflict, with a critical value of 2s-0s being selected. According to Van Der Horst (1990), the recommended threshold value for PET is also between 2s-0s. According to Ohta (1993), Taieb-Maimon & Shinar (2001), Evans (1991), and Michael et al. (2000), the PET indicator's threshold value can differ based on critical situations such as comfort, danger, minimum safety, and situations where it should not be considered safe enough to prevent possible conflicts. The selected threshold criteria of Van Der Horst (1990) fits within these situations.

TABLE 2: Overview temporal and spatial indicators (Ferreira et al., 2017)

Indicator	Definition	Limitations	Advantages	Suitability for collision type	Threshold value
Time-to-collision (TTC) or Time-measured-to-collision (TMTC)	The time until a collision between the vehicles would occur if they continued on their present course.	Assumption consecutive vehicles will keep constant speed. Ignorance of potential conflicts due to acceleration /deceleration. Magnitude of the crash not severity. TTC cannot be estimated when leading vehicle is faster than the following	More frequently used in practice than PET or TA due to theoretical issues. Is more informative than PET. Avoidance systems/drivers assistance used TTC before for warnings.	Rear-end, turning, weaving, hit objects, crossing and hit pedestrian.	2-0 seconds

Indicator	Definition	Limitations	Advantages	Suitability for collision type	Threshold value
Post-encroachment Time (PET)	The time between the moment that a road user leaves the area of potential collision and the other road user arrives the collision area	Only useful in the case of transversal trajectories. Cannot reflect changes with dynamics of safety critical events over larger area. Level of severity not taken into account.	PET is more appropriate for intersecting conflicts than TTC. PET represents the drivers behaviours	Mainly for right angle crossing crash hit pedestrian, merging, diverging, head on.	2-0 seconds

3.7.2. Deceleration & distance indicators

Deceleration-based proximal indicators use the deceleration rate during an emergency to define if a situation is dangerous. The distance-based indicator finds its fundaments under the available space to avoid a collision.

According to Abdel-Aty et al. (2023), the following parameters are effective and valuable to decide about safety performances: time-to-collision, proportion of stopping distance (PSD) and deceleration rate to avoid a crash (DRAC). DRAC is defined as "differential speed between a following vehicle and its corresponding subject vehicle divided by their closing time. This indicator is relevant because it is considered suitable for pedestrians getting hit and differentials in speed (Ferreira et al., 2017). During a square green traffic cycle different speeds on the intersection are noticeable between pedestrians and cyclists. One limitation of this indicator is that it only identifies speed differences and not potential conflicts. However, a higher speed difference indicates a greater risk of injury and damage in the event of a crash. Archer (2005), Guido et al. (2010), and AASHTO (2004) state that the threshold value for DRAC is between 3.40 m/s^2 and 3.35 m/s^2.

PSD stands for "the ratio between the remaining distance to the potential point of collision and the minimum acceptable stopping distance (Ferreira et al., 2017). Although an exact threshold value is not given for the PSD indicator (Guido et al., 2010; Allen et al., 1978; and Astarita et al., 2012), the formula is based on the remaining distance to the potential collision point divided by the minimum acceptable stopping distance. A higher value is considered safe. PSD is much more difficult to calculate and is not programmed in the analysing software. It will not be possible to take this proximal indicator into account during the analysing phase.

TABLE 3: Overview of deceleration and distance indicators (Ferreira et al., 2017)

Indicator	Definition	Limitations	Advantages	Suitability for collision type	Threshold value
Deceleration Rate to Avoid the Crash (DRAC)	Differential speed between a following/response vehicle and its corresponding subject/lead vehicles divided by their closing time	Can not identify potential traffic conflict situations and lateral movements.	Considers differential speeds and deceleration in traffic	hit pedestrian, merging and diverging manoeuvres	3:40 m/s²-3:35m/s²
Proportion of Stopping Distance (PSD)	Ratio between remaining distance to potential point of collision and the minimum acceptable stopping distance	Provides higher percentage of interactions and time exposure than TTC and DRAC and so less focus on specific safety problem	Single vehicle conflict with fixed or unfixed objects can be evaluated	Hit object or overturning	No exact threshold value

Another parameter can be the deceleration-based surrogate safety measure (DSSM). Its definition is "collision risk with a ratio of maximum braking performance of the subject vehicle to a required deceleration rate to avoid a crash when the leading vehicle abruptly reduces its speed with maximum braking performance". (Kinero, 2021) The threshold value for this indicator is 1 (Donghoun et al., 2018)). The situation is considered unsafe when the DSSM value exceeds the critical threshold. Conversely, a value lower than 1 indicates a safe situation.

3.7.3. Other indicator

Delta-V investigates "the relative change in velocity in pre-crash and post-crash", Mullins et al. (2020). If a crash is registered, this indicator can point out the collision's severity. An exact threshold value is not given for this indicator. When the outcome value of the formula is lower, higher speeds were involved in the crash and so a higher severity (Shelby, 2011). According to Daniels et al. (2017), the extended Delta V is derived from the Delta V indicator but adds an extra dimension. "It integrates the proximity to a crash as well as the outcome severity in the event a crash would have taken place", Daniels et al. (2017). Although the extended Delta V is not included in the software and so won't be used.

Pedestrians and cyclists have designated safe space, and collisions may occur when they enter each other's space. The shape of this space varies depending on the type of road user, speed, and pedestrian volume (Wang et al., 2024). Pedestrians have a semi-circular area, while bicyclists have a semi-elliptical one. The dimensions of the safe space increase with higher speeds, but decrease with increased pedestrian traffic volumes. When examining data, it is valuable to consider threshold values, although it is unclear how to incorporate this into software processing tools. This may be a limitation of the research.

3.7.4. Additional information

Extra information that can be derived from the UAV footage is the origin and destination data (OD). It provides information about the traffic flow, where details are given between a starting point and another end location (Leigh & Lovelace, z.d.). It provides an image of where the traffic is heading and which part of the infrastructure is emphasised.

The Surrogate Safety Assessment Model (SSAM) is a predictor of the roads' safety before a crash. It is "a software that can identify, classify and evaluate traffic conflicts in vehicle trajectory data from microscopic simulations models", Chen (2022). Real data from the drone footage can be put in the simulation model and used as an estimator.

3.8. Possible cases to review

The intention is to review quick-win infrastructural interventions, i.e., low-budget interventions with a (high) potential impact on traffic safety. A green traffic light cycle is therefore selected. Possible areas are intersection in the close proximity of school zones, bicycle streets, important access roads, 30km/h zones, … .

An email has been sent to cities and villages to receive information about infrastructural interventions in the period of January 2024. AWV (Agentschap Wegen en Verkeer - Agency Roads and Traffic) have also been contacted for information about newly developed interventions that will be implemented in the near future. Specifically to Liessa Iliaens (responsible for safety and design), Claudia Juvyns (AWV Limburg) and Jens Van Engeland (AWV Limburg). After establishing contact, the following cases are considered as valuable opportunities for this research.

The research initially planned to include a before-and-after study. However, due to the time frame for implementing the green traffic light cycle and the deadline for this master's thesis, no suitable case could be found.

As mentioned in the research objectives and questions, green traffic light cycles at other intersections will be investigated. The following scenarios are considered based on the size of the intersection: compact on the one hand and extensive on the other. This can partially be linked to the time required to clear the intersection. This avoidance time mainly depends on the speed used on the access roads to the intersection. A minimum time of 1s is required for a design speed of 30km/h which is used on smaller roads lower in the road network and a minimum of 5s at design speeds of 80km/h which is used on bigger roads positioned higher in the road network. (TU Delft, n.d.). The cases are V016205 (Limburg, Hasselt); V016207 (Limburg, Hasselt) and V016203 (Limburg, Hasselt. Furthermore, it is important to check the corresponding geozones in which the cases are situated. They inform if it is allowed to fly a drone in that area and which additional rules have to be followed.

4. Methodology

4.1. Research design

The first step of this research was a literature review. The current state of analysing and judging infrastructure safety is by looking at the number of crashes and their severity during a period of 3-5 years (531-score). This type of reactive approach will not be used during this research. The literature provided more information about drone technology and proximal factors that can be used to decide if the road is safe in a shorter time frame. The literature

gave an overview of the current problems in Belgium. In the context of Vision Zero and the safe system approach, the government stimulates innovative ways and technologies to improve traffic safety. The green traffic light cycle is one of those ideas. Other search terms that were used for green traffic light cycles in the literature were pedestrian phase, exclusive pedestrian phase, cycling phase, pedestrian scramble, intersection scramble, diagonal crossing, scramble intersection, All-way walk, Scramble crossing, and Barnes dance.

The research process follows the funnel structure describing a general community problem. The further the research evolves the more specific the information will be. The goal is to evaluate specific, smaller, infrastructural interventions to test the method of using drone technology, a proactive approach. If proof exists that the process works, it can be again connected to the broader community.

Drone technology is a rather new concept and is in total development. The goal is ultimately to work with this idea on a national level and improve the safety according to the mindset of the safe system approach.

After the locations are selected, drone footage will be captured. The selection process of the locations can be found under chapter

Possible cases to review. The software will indicate and classify the road users and apply the proximal factors. By looking at the parameters of the indicators, the safety of the infrastructure can be decided. The software program to be used is called 'Data from Sky'. According to Data from sky (2024), it is possible to "infuse your simulation models with the most accurate real-world calibration data". The tool provides precise analytics on speed, acceleration, timing, O/D matrices, capacities, and safety analysis, with pinpoint accuracy of 95% and 30cm localization. The traffic video analytics can investigate intersections, roundabouts, highways, and crosswalks. This research investigates intersections and is relevant. The software employs a combination of AI and image processing, which mitigates the limitations of traditional methods (Data from sky, 2024). The software programme will provide numerical data, tables and graphs based on the footage captured by the drone. The research will be therefore mainly quantitative in nature. The proximal factors discussed in the literature are the following: Time-to-collision, Post-encroachment time, Proportion of stopping distance, Deceleration rate to avoid a crash, Deceleration based surrogate safety measures, Delta V, Origin Destination and the estimation model Surrogate safety assessment model. Although they are all relevant and interesting to investigate, a shorter selection will be made. The proximal indicators used in the analysis by the software are time-to-collision, post-encroachment time, delta V, and Origin Destination Matrix.

Validity and reliability must be guaranteed in this research. In some of the proximal indicators, factors of error are included. The research of Al Sobky (2023) mentions drone instability when capturing footage. It is impossible to keep the drone in the exact location during the period of data collection. It causes vertical and horizontal deformations. An error formula is provided in the calculations to make the data more reliable. This has to be included not to make this a research limitation. Another difficulty can be the privacy law. As was already mentioned in the literature review, different types of privacy exist. When capturing the footage, attention should be paid that privacy is respected and the drone stays out of the restricted zones.

4.2. Drone investigation guide

4.2.1. Preparations

This chapter is dedicated to the preparations of the data collection. It is crucial to establish clear agreements beforehand, carefully deliberate on decisions, and thoroughly verify every aspect of the data collection process to prevent any unforeseen complications from arising. The drone guide follows the advice of European Regulations for drone operations and suggests the structure below; written by Skeydrone (2023).

I. Plan
    A. Check your position
    B. Check relevant Geozones according to the flight plan

II. Category and authorisation
    A. Comply with each Geozone and their rules
    B. Contact the Geozone Manager and comply with their additional rules
    C. Request flight authorisation if necessary
III. Fly

4.2.2. Location

The selection process is based on the size of the intersection: compact and extensive ones. This corresponds to cases V016207, V016205, and V016203. After examining the designated areas for drone flights, the next step is to determine the permissibility of flying and any further regulations. This information has been provided directly by Skeyes (2023).

Case V016207 corresponds to location R70 Kolonel Dusartplein & N702 Koning Boudewijnlaan in Hasselt. There are no specific conditions or additional rules implied in this Geozone. Case V016205 is situated at the intersection of R70 Guffenslaan & Kunstlaan in Hasselt. This case also has no specific restrictions. The last case V016203 located on R70 Leopoldplein; N20 Luikersteenweg; N80 Sint- Truidersteenweg does not have any predetermined conditions that need to be considered. A remark must be made that these conditions are concluded during the preparation phase. Prior to the collection date and on the day itself, the terms will be reviewed again to ensure they have not changed. It can happen that the person responsible for that specific zone has to be contacted if rules change and apply on the day of the flight itself. There is no predefined flight path for this study as the drone will gather data by hovering over the intersection in the locality.

The three sites are located on the inner ring road of Hasselt. At the intersection of sites one and three there are important access roads. The intersection at location two consists of the ring road and a smaller cycle path where cyclists have priority. The inner ring has a speed limit of 50 km/h, two lanes and one direction.

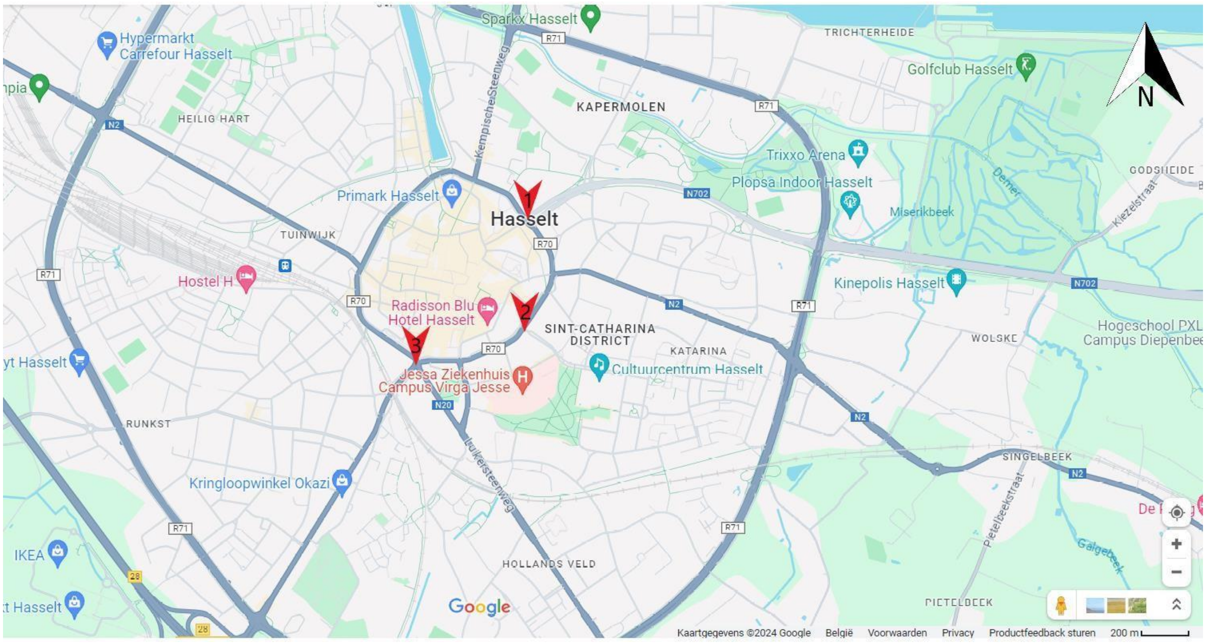


FIGURE 4: Macro situation of investigation area (Google Maps and own edit, 2024)

The first location, R70 Kolonel Dusartplein & N702 Koning Boudewijnlaan, is located in the built-up area of Hasselt. Koning Boudewijnlaan is a major access road coming from Genk and Diepenbeek in the east. On the intersection there is no indication or signal that there is a square green traffic cycle. The information in the location sheet below (TABLE 4: Location sheet case Kolonel Dusartplein and Koning Boudewijnlaan (Illiaens and own edit, 2024)) is provided by L. Illiaens from Agency of Roads and Traffic in Belgium – AWV (personal communication, 2024).

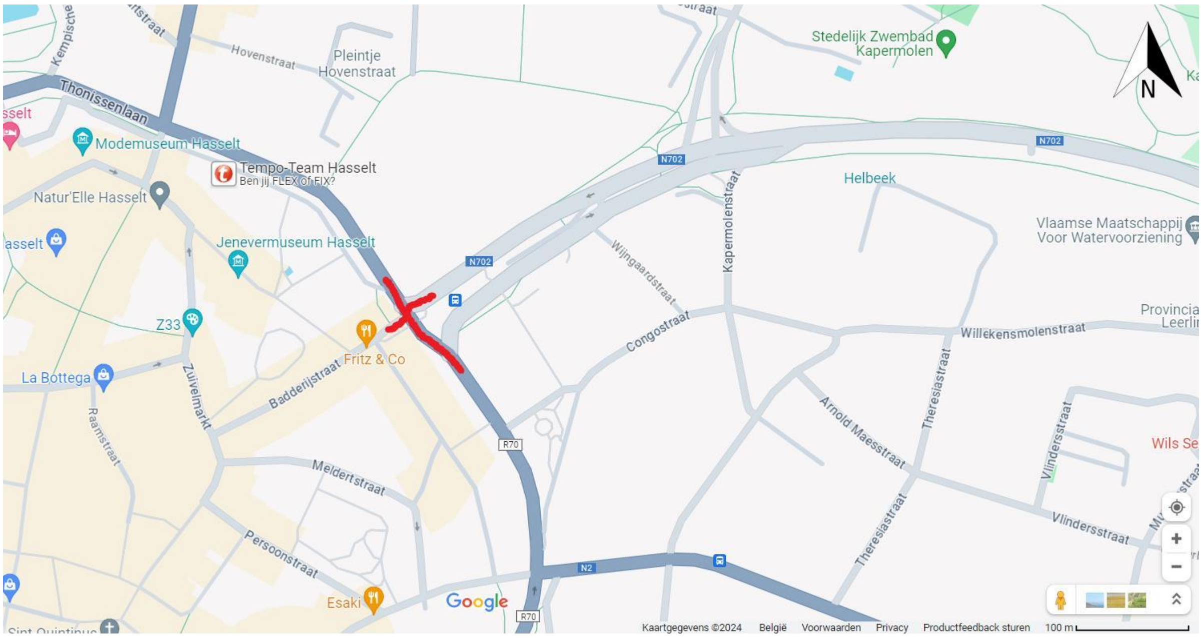


FIGURE 5: : Meso situation of investigation area Kolonel Dusartplein and Koning Boudewijnlaan (Google Maps and own edit, 2024)

TABLE 4: Location sheet case Kolonel Dusartplein and Koning Boudewijnlaan (Illiaens and own edit, 2024)

Location sheet	Information
Identification number	V016207
Intersection	R70 Kolonel Dusartplein & N702 Koning Boudewijnlaan
Municipality	Hasselt
Province	Limburg
Within or outside built-up area	Within built-up area
Type of road users	Vulnerable road users & motorised traffic
Type of movements and other characteristics	Confusing design for vulnerable road users to cross the intersection
Speed road 1	50km/h
Speed road 2	50km/h
Walkway	Yes and separated
Cycle lane	Partly separated, partly on the road
Drone flying restrictions	No specific restrictions
Square green indication	No
Time and weather during indication	

The second location, N20 Luikersteenweg & N80 Sint-Truidersteenweg, is situated in the urban area of Hasselt. Sint-Truidersteenweg is a significant access road from Alken and Sint-Truiden in the south. There is no indication or signal at the intersection that there is a green traffic cycle for cyclists. More information can be found in the location sheet below (TABLE *5*: Location sheet case Luikersteenweg and Sint-Truidersteenweg (Illiaens and own edit, 2024)).

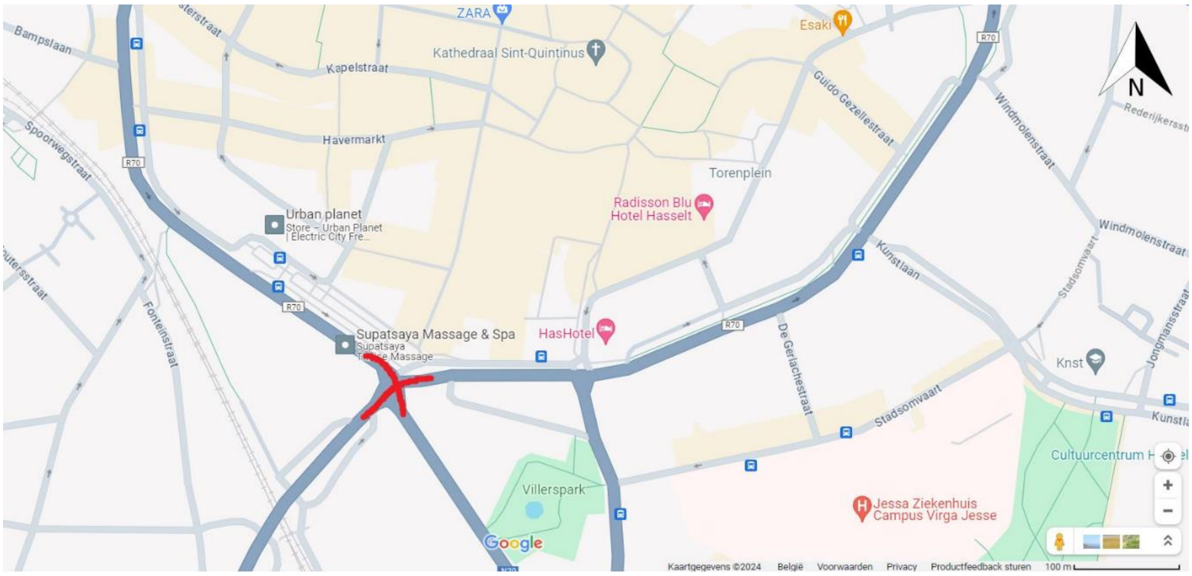


FIGURE 6: Meso situation of investigation area Luikersteenweg and Sint-Truidersteenweg (Google Maps and own edit, 2024)

TABLE 5: Location sheet case Luikersteenweg and Sint-Truidersteenweg (Illiaens and own edit, 2024)

Location sheet	Information
Identification number	V016203
Intersection	N20 Luikersteenweg & N80 Sint-Truidersteenweg
Municipality	Hasselt
Province	Limburg
Within or outside built-up area	Within built-up area
Type of road users	Vulnerable road users & motorised traffic
Type of movements and other characteristics	
Speed road 1	50km/h
Speed road 2	50km/h
Walkway	Yes and separated
Cycle lane	Partly separated, partly on the road
Drone flying restrictions	No specific restrictions
Square green indication	No
Time and weather during indication	

The third location, R70 Guffenslaan & Kunstlaan, is situated in the urban area of Hasselt. Kunstlaan is a narrow cycle lane where bicycles have priority over motorised traffic. Vehicles must remain behind the bicycles until the ring road, which may result in interesting traffic situations during a square green traffic cycle. However, there is no indication or signal at the intersection that a square green traffic cycle is in effect. More information can be found in the location sheet below (TABLE *5*: Location sheet case Luikersteenweg and Sint-Truidersteenweg (Illiaens and own edit, 2024)).

FIGURE 7: Meso situation of investigation area Guffenslaand and Kunstlaan (Google Maps and own edit, 2024)

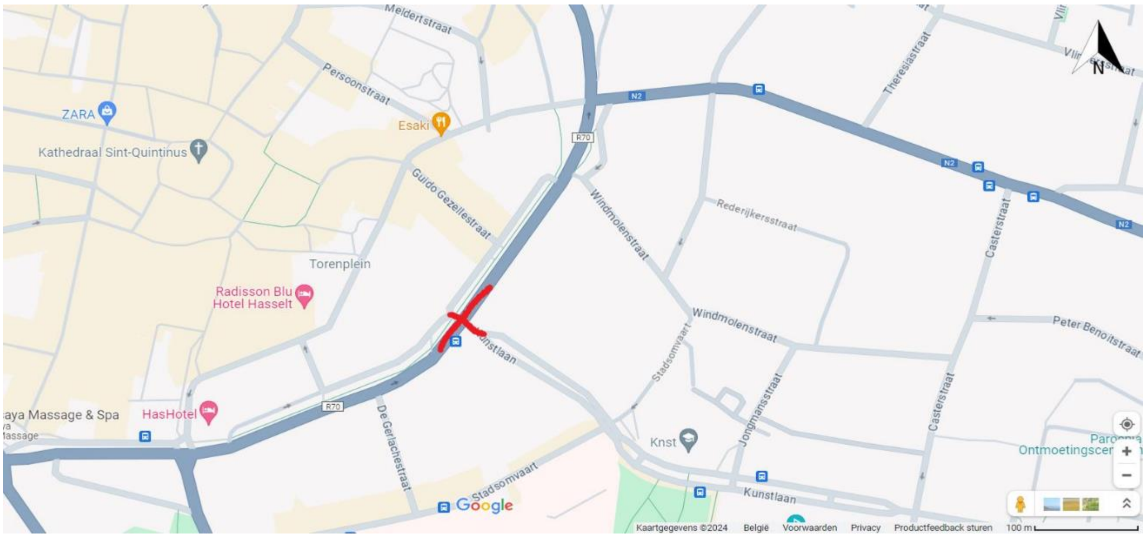


TABLE 6: Location sheet of case Guffenslaand and Kunstlaan (Illiaens and own edit, 2024)

Location sheet	Information
Identification number	V016205
Intersection	R70 Guffenslaan & Kunstlaan
Municipality	Hasselt
Province	Limburg
Within or outside built-up area	Within built-up area
Type of road users	Vulnerable road users & motorised traffic
Type of movements and other characteristics	One of the access roads to the inner ring is a cycling road where bicycles have priority. This intersection is of interest for investigating the square green cycle due to the unique bicycle movements that occur there.
Speed road 1	50km/h
Speed road 2	30km/h
Walkway	Yes
Cycle lane	Partly separated, partly on the road
Drone flying restrictions	No specific restriction
Square green indication	No
Time and weather during indication	

Information flyers were distributed at the three locations mentioned above to inform citizens and companies about the upcoming data collection. The flyers were distributed one week prior to the data collection. The provided information includes the organization conducting the research, the date of data collection, the specific images to be collected, the research objectives, the measures taken to ensure privacy, and the duration of drone surveillance. The information was presented in both Dutch, the primary language in Hasselt, Flanders, Belgium, and English for non-Dutch speakers. The flyer example can be found in the enclosure chapter of this paper.

4.2.3. What will be filmed

As already mentioned, the drone will not follow a path nor cover large distances. The UAV will hover above an intersection and film the movements of the road users. These traffic participants can be pedestrians, e-steps, cyclists, speed pedelecs, mopeds and motorised vehicles. Later during the data processing the proximal factors will be applied on the footage.

4.2.4. Material

Prior to the data collection, a drone certificate must be obtained. The individual responsible for creating the images possesses a certificate ranging from A1 to A3.The material will be checked beforehand to ensure that all operations are functioning as intended. The drone model that will be used is the DJI mini 3 Pro.

4.2.5. When will the data collection take place

The data collection takes place in March over a two-week period to allow for selection of an ideal flying day. The day is chosen based on weather conditions, with consideration given to wind strength and dryness to ensure the drone can hover stably in the air. To determine whether weather conditions were suitable for data collection, two sources were consulted prior to the day of collection. UAV Forecast (2024) provided information on wind, wind gusts, rain, chance of rain, visibility, and Kp, and suggested whether it was suitable to fly. All of these factors are important to consider for successful data collection. Windy (2024) provided similar information on wind, wind gusts, and wind direction. The second source was consulted to re-validate the information.

The rush hour was filmed at all three locations. On Monday 4th March at around 4 o'clock in the afternoon, the intersection of Dusartplein and Koning Boudewijnlaan was filmed. The intersection of Luikersteenweg and Sinter-Truidersteenweg was recorded on 5th March at 8 o'clock. Finally, on Thursday 7th March at 8:30 am, the intersection of Kunstlaan and Guffenslaan was filmed.

4.2.6. On site

During the preparations a detailed look has been taken to the flight Geozones and corresponding regulations to that area. On site itself, another look will be taken at the possible dangers. It is compared with the knowledge acquired in advance and an assessment is made for any hazards that were not previously apparent or mentioned.

On the day of the data collection itself, Loran Reynaerts will be responsible for the data collection and must guarantee the safe usage of the equipment and of the surroundings. It means following the regulations of the Geozones, respecting the limitations of the material, being aware of surrounding dangers and acting accordingly to the situations presented.

Before and after every flight a condition check of the material will be carried out. This is to guarantee safety - of the flight, - for the nearby citizens, - for the researchers themselves and for qualitative data.

Once the drone's condition has been checked and approved, it will be launched. The UAV is placed in the proper location (correct coordinates). When it is in a stable position, the recording can start. The batteries allow a maximum flight time of 38 minutes. In order to launch and land the drone safely, the data recording itself will take no longer than 20 minutes. The drone must be visible to the pilot at all times. The pilot can monitor the drone via a display on the control unit. The exact position of the camera can also be controlled in this way. When the recording is finished, the UAV is landed. Immediately after landing, the drone's condition is checked to ensure that the next data collection can be carried out safely. The above procedure is executed each time measurements are taken.

4.2.7. After procedure

After collecting the data on site, the first step is to process it. This involves several stages, beginning with checking the quality of the material to ensure it can be used for further analysis. This includes stable recordings, unobstructed images, and complete footage. Once the data has been received, one person is responsible for blurring private properties before it can be shared with other researchers and reviewed in the paper. To ensure the absolute privacy of individuals recorded on in the public spaces.

After completing this step, the GPS coordinates must be georeferenced. This is achieved by selecting the precise area of roads in the image frame and linking at least four coordinates between the image frame and real-world UTM coordinates. Only then can the data be considered meaningful and further results can be derived, such as applying proximal indicators.

The software 'Data from Sky' is used for this purpose. With this step completed, the analysis can begin and the results can be documented.

5. Results

5.1. Location 1: Dusart

5.1.1. Modal split

The following graph displays the modal split for the first location over a brief 30-minute period during the evening peak. The results presented below are therefore specific to the time of investigation and not generalizable to the entire day. Pedestrians are the most common mode of transportation on Dusart square (during the recording time), accounting for 51% of the total. Cars and bicycles follow, representing 29% and 13% respectively. Heavy vehicles and motorcycles are the least used modes of transportation. The area is home to schools, bars, restaurants, and leads into the city centre, making the distribution of modes of transportation logical. It is important to note that the modal split was established using entry and exit gates. It is possible that some registered road users may be misidentified, which could result in minor discrepancies in the data. However, the overall differences between categories will remain consistent.

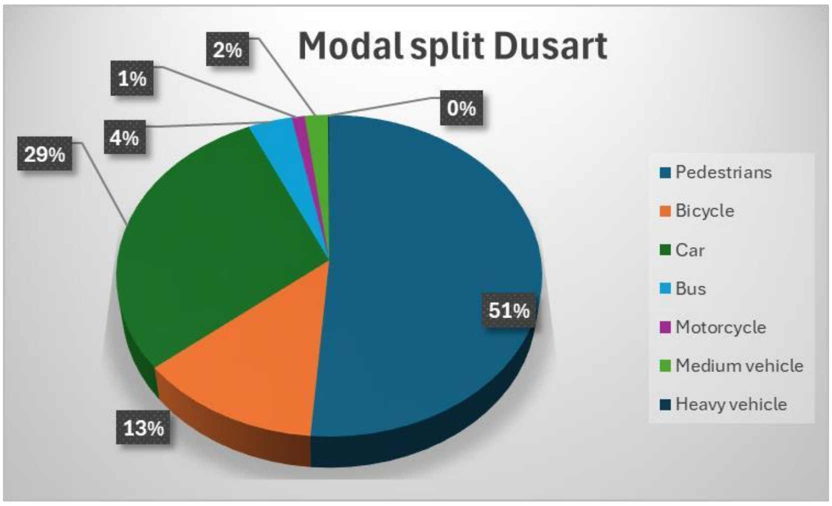


FIGURE 8: Modal split Dusart (Own edit, 2024)

5.1.2. Origin and destination

5.1.2.1. Vulnerable road users

As mentioned in the Modal split chapter, pedestrians and bicycles are highly represented on Dusart Square and are categorized as Vulnerable Road Users (VRUs). The aerial map below (FIGURE 9: O/D Matrix VRU aerieal map Dusart (Own edit, 2024)) shows the origin and destination of these VRUs. The map displays the routes of VRUs approaching from different directions: north 1 (blue lines), north 2 (orange lines), east (purple line), and south (red lines). There are almost equal numbers of VRUs heading from North 1 towards the city centre (blue line, 67%) and from the city centre towards the bus stops (red line, 60%). A significant number of VRUs travel from north 2 to the south (orange line 84%). It can be inferred that the majority of travel occurs between the north and south. This is a logical outcome as the northern route is a crucial access road and the primary attractions are situated in the north and south (city centre). In the table below (TABLE *7*: O/D Matrix VRU Dusart per hour (Own edit, 2024)) the exact number VRUs per hour are written.

TABLE 7: O/D Matrix VRU Dusart per hour (Own edit, 2024)

O/D matrix VRU Dusart	Exit Gate 9 (tag: North)	Exit Gate 11 (tag: North 2)	Exit Gate 13 (tag: East)	Exit Gate 15 (tag: South)	Exit Gate 17 (tag: West)
Entry Gate 8 (tag: North)	0	0	0	44	22
Entry Gate 10 (tag: North 2)	0	0	1	32	4
Entry Gate 12 (tag: East)	2	10	0	2	38
Entry Gate 14 (tag: South)	36	14	0	0	0
Entry Gate 16 (tag: West)	0	0	0	0	0

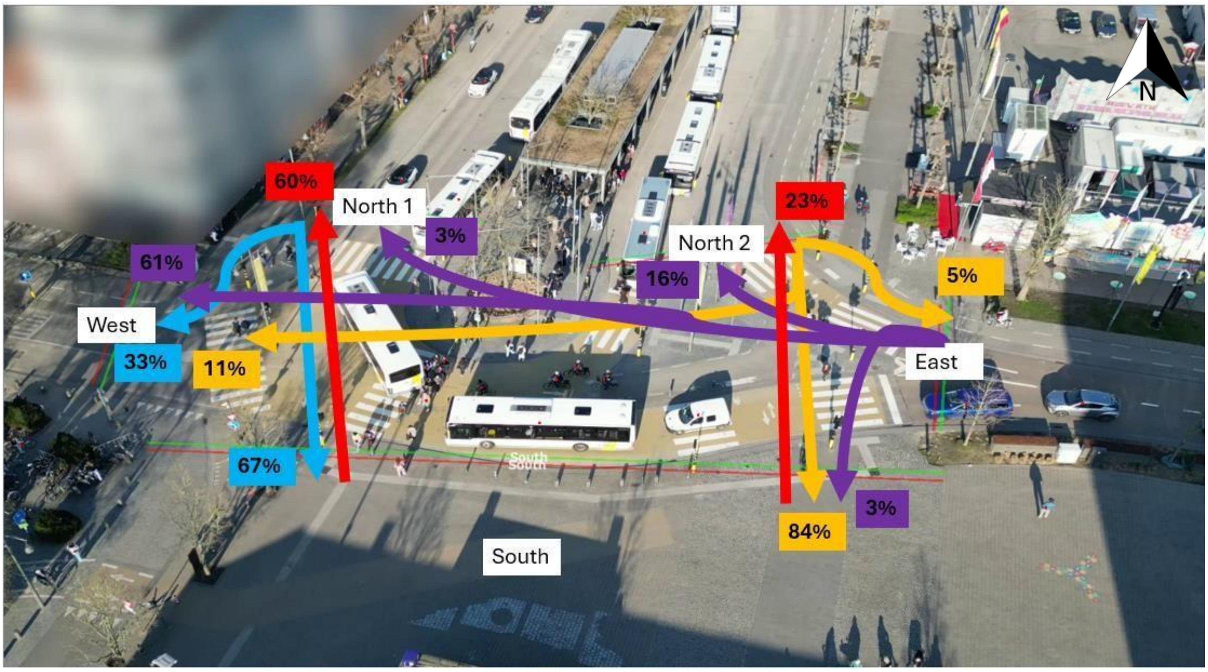


FIGURE 9: O/D Matrix VRU aerieal map Dusart (Own edit, 2024)

Legend: blue= north 1, orange= north 2, purple= east, red= south

5.1.2.2. Motorised vehicles

Other lines are visible for the motorised vehicles on the Dusart square in comparison to VRUs. The aerial map displays the routes of VRUs approaching from different directions: north 1 (blue lines), north 2 (orange lines), east (purple line), and south (red lines). Because the inner ring circle of Hasselt is one direction and follows the route anti-clockwise (from east to west), most of the traffic is distributed from the east. Motorised vehicles are permitted on the visible lines at Dusart square. Due to the one-way inner ring circle in Hasselt, traffic from the east is primarily distributed, following the anti-clockwise path (west to east). This traffic typically continues westward on the inner ring circle. The north 1 and north 2 roads only allow public transport in both directions. As a result, all traffic from north 2 is directed towards the west. Motorised traffic from the north and south is required to drive west.

TABLE 8: O/D Matrix Motorised traffic Dusart (Own edit, 2024)

O/D Matrix Motorised Dusart	Exit Gate 9 (tag: North)	Exit Gate 11 (tag: North 2)	Exit Gate 13 (tag: East)	Exit Gate 15 (tag: South)	Exit Gate 17 (tag: West)
Entry Gate 8 (tag: North)	0	0	0	0	150
Entry Gate 10 (tag: North 2)	0	0	0	0	33
Entry Gate 12 (tag: East)	22	111	0	0	288
Entry Gate 14 (tag: South)	0	0	0	0	36
Entry Gate 16 (tag: West)	0	0	0	0	0

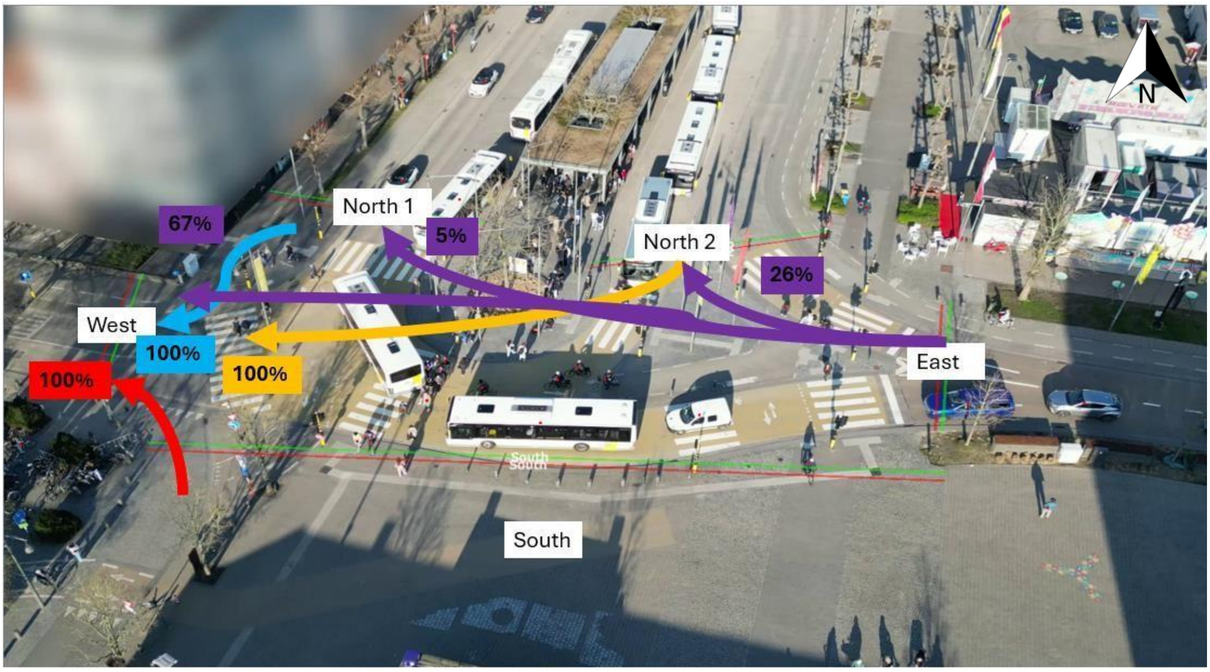


FIGURE 10: O/D Matrix Motorised traffic aerial map Dusart (Own edit, 2024)

Legend: blue= north 1, orange= north 2, purple= east, red= south

5.1.3. Occuring speeds

The speeds at which motorised vehicles travel are as follows. The average speed recorded on Dusart Square was 25 km/h. The maximum speed was 39.8 km/h. This is still lower than the speed limit at the junction, which is 50 km/h. The V85, or what 85% of the drivers drive, is 23.2 km/h. This is again lower than the permitted speed.

The map below (FIGURE 11: Maximum speeds Dusart (DFS and own edit, 2024)) visualises the maximum speeds, with red indicating speeds closest to 50km/h and green indicating lower speeds. It is worth noting that no one violated the maximum speed limit. Higher speeds were observed at the west end of Dusart Square, which is a logical occurrence as people are already accelerating for a certain distance and there are no situations that require them to stop again. Therefore, higher speeds can be reached.

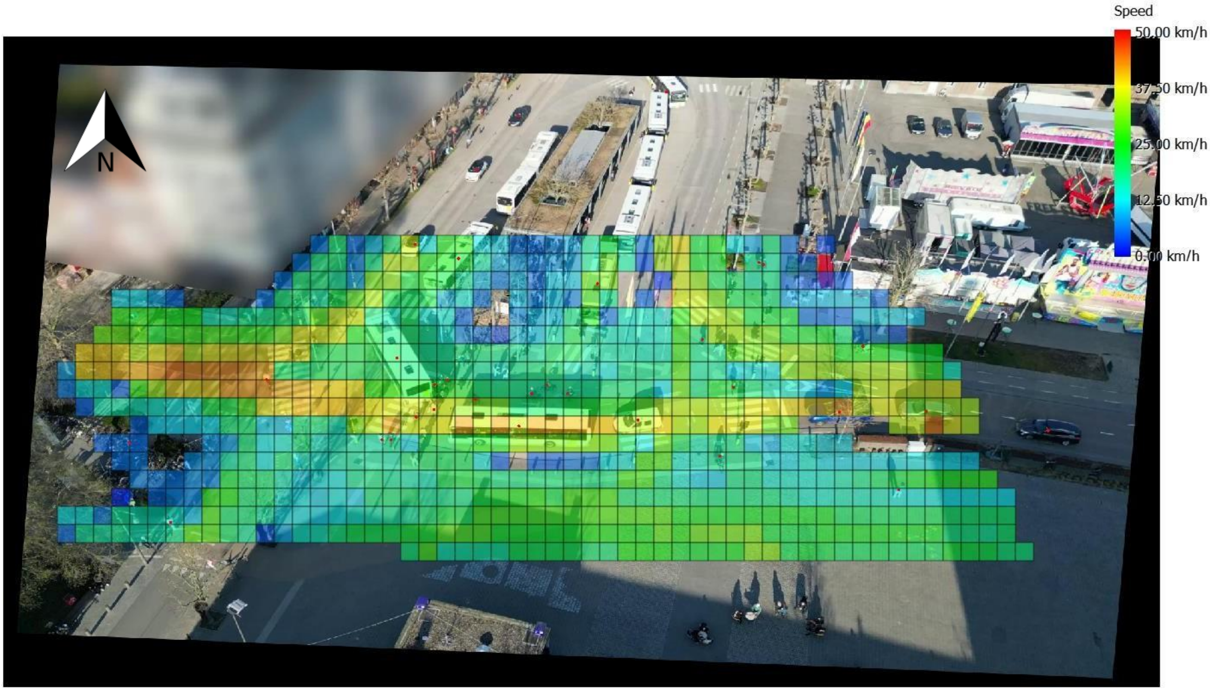


FIGURE 11: Maximum speeds Dusart (DFS and own edit, 2024)

The map below (FIGURE 12: Average speeds Dusart (DFS and own edit, 2024)) displays average speeds, using the same colour scale as the previous map. The relatively low average speeds of motorised traffic, is due to the necessity of stopping at traffic signals. The speeds are a higher for motorised traffic, in comparison to lower speeds in areas with vulnerable road users such as pedestrians and cyclists, including the bus stop, walkways, and the square in the south.

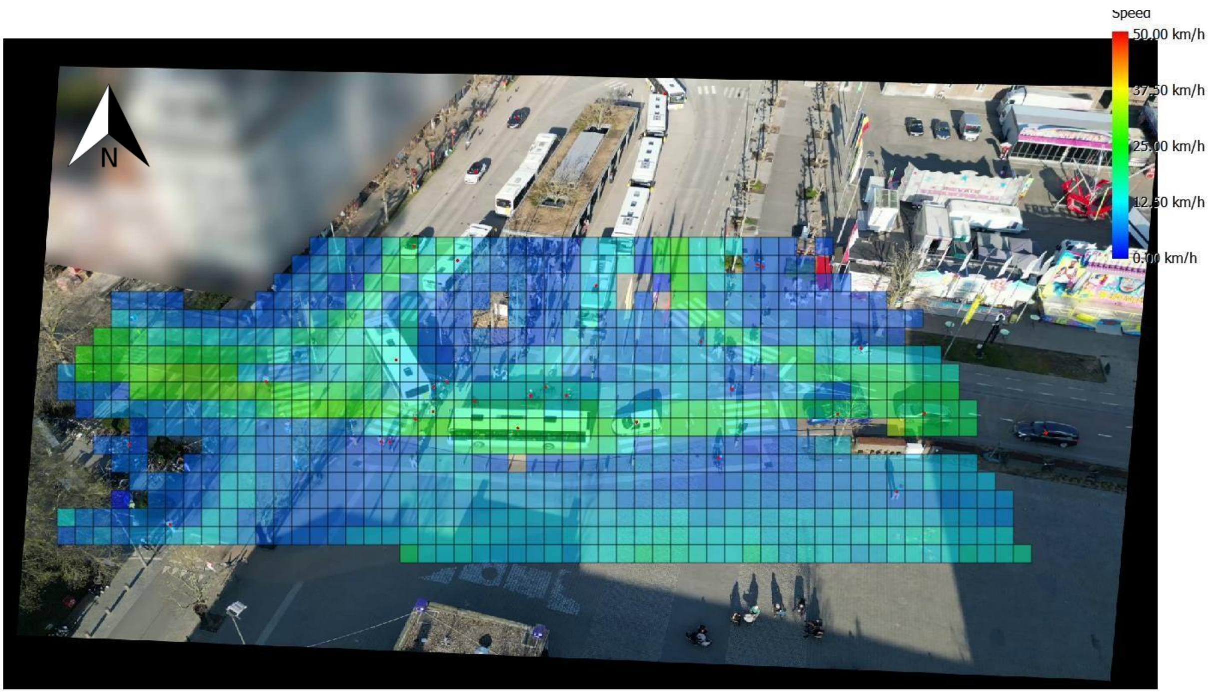


FIGURE 12: Average speeds Dusart (DFS and own edit, 2024)

5.1.4. Trajectory of the road users

The map illustrates the trajectories of road users on Dusart square during the recorded period. Vulnerable road users, represented in blue, include pedestrians and cyclists. Motorised traffic, represented by purple lines, includes cars, buses, motorcycles, medium vehicles, and heavy vehicles. Motorised vehicles are restricted to designated roads. Vulnerable road users can be found on walkways and cycle lanes. The VRU patterns on the square in the south are mixed, because free movement is allowed there. To get a better understanding of the crossing facilities, one can take a closer look. Dusart Square has a green traffic light cycle. The main crossings occur at the pedestrian crossings, with only a few small blue lines visible in between. The option of diagonal crossing on the intersection itself is not fully utilised. Upon examination of the area outside the intersection, it becomes evident that the southern square, situated below the main road, crossings of VRUs do not have a clear pattern. Instead, the blue lines appear to crisscross each other in a diagonal manner.

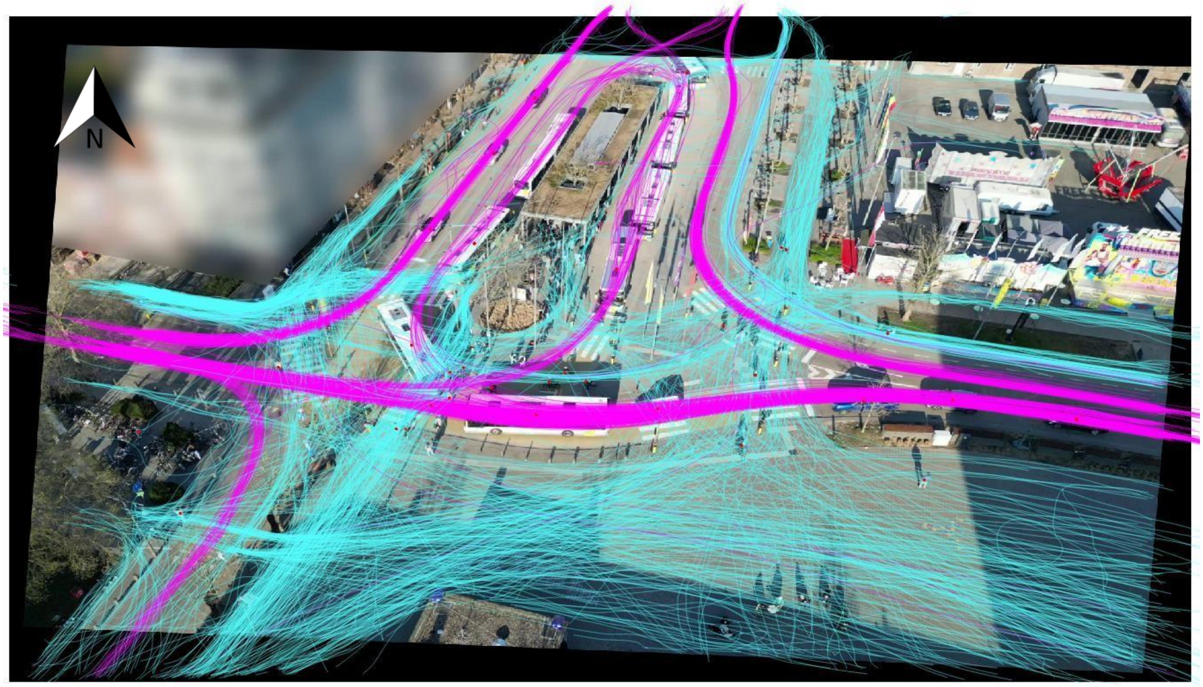


FIGURE 13: Trajectory map Dusart (DFS and own edit, 2024)

The trajectory map (FIGURE 13: Trajectory map Dusart (DFS and own edit, 2024)) and the VRU O/D matrix (FIGURE 9: O/D Matrix VRU aerieal map Dusart (Own edit, 2024)) can be combined, as shown below (FIGURE 14: Trajectory map with O/D matrix Dusart (DFS and own edit, 2024)). The largest VRU streams travel between North 1 and South (city centre). Based on the trajectory lines, it is noticeable that they are travelling to and from the centre of the island (bus stop). The conclusion of trajectory lines can be validated by the origin and destination of the VRUs' traffic. The centre island attracts the greatest number of VRUs for the northern part of the road. Another significant stream comes from the East towards the West, using the standard route across pedestrian crossings and cycle lanes. It can be observed that cyclists tend to adopt diagonal trajectories between the pedestrian crossings on the eastern side of the road. In order to navigate the crossing, cyclists must slow down, which necessitates a more curved trajectory. This isn't visible with the trajectories. This could be attributed to the fact that cyclists wish to maintain a consistent speed and use a straight line. In the eastern part of the intersection, the O/D lines may suggest a diagonal crossing during the green phase. A high percentage, 84%, of vehicles are travelling from north 2 towards the south. On the intersection, diagonal crossing is not employed; rather, it is utilised on the southern square below the intersection. The western part of the intersection does not require diagonal crossing based on the O/D information. The trajectory lines demonstrate that the normal crossing paths are utilised. One potential reason for the lack of diagonal crossing at the intersection is the presence of poles that divide the road and the southern square.

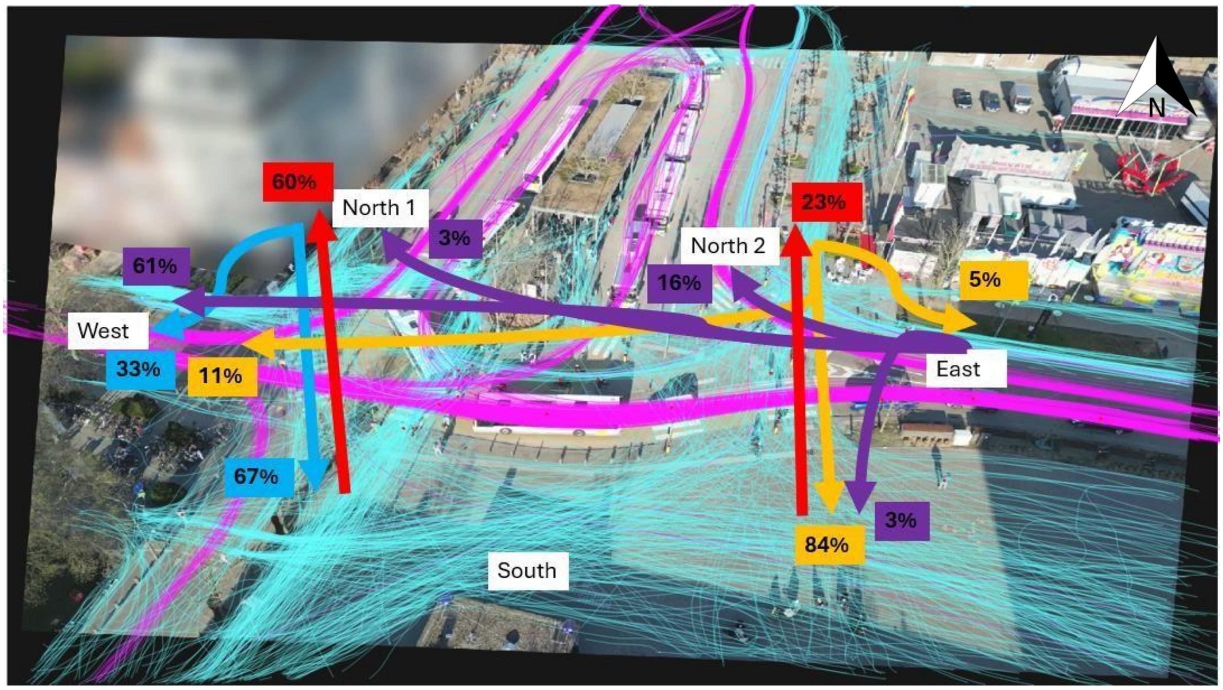


FIGURE 14: Trajectory map with O/D matrix Dusart (DFS and own edit, 2024)

5.1.5. Proximal indicator TTC

According to the TTC data of Dusart Square, a critical conflict occurred between a bus (ID260) and a car (ID267), which was registered as a crossing conflict. Although there was no collision, the TTC data recorded it as having the highest seriousness score.

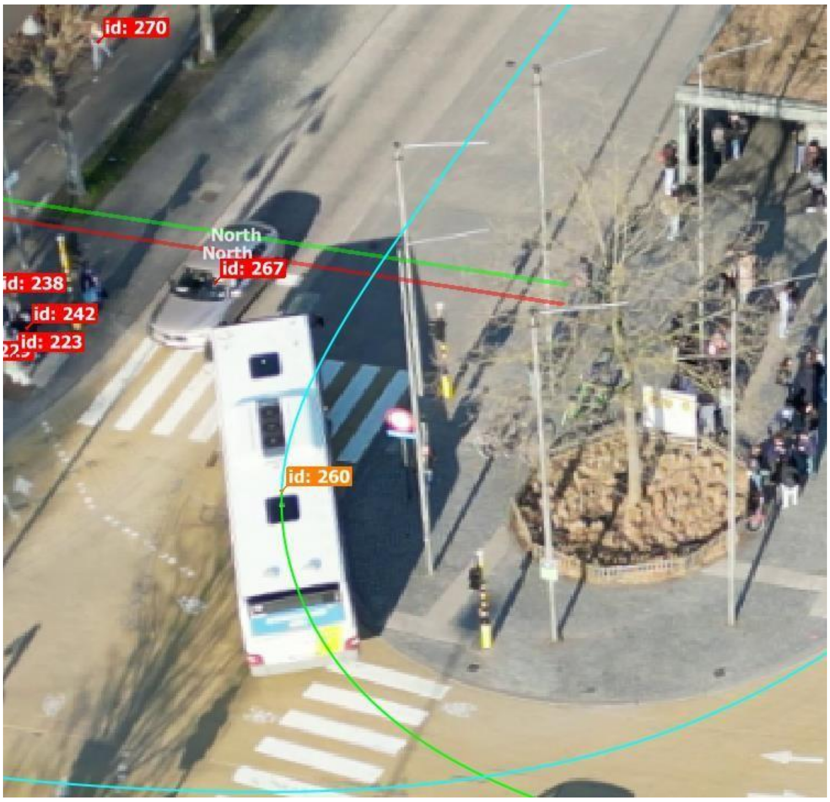


FIGURE 15: Critical conflict point TTC Dusart (DFS and own edit, 2024)

5.1.6. Conflict points TTC

The previous chapter, Proximal indicator TTC, analysed the highest seriousness score, which is based on the probability of a conflict and the severity, for the TTC parameter, which was recorded as a crossing conflict. The map below shows a grid map based on the TTC indicator. The legend is constructed using threshold values from the literature and is as follows: a time of 0s-1s is a critical TTC score (red), between 1s-1.9s is considered moderate (yellow), and >2s indicates a non- dangerous situation (green to blue). The video recordings indicate that the areas with the highest concentration of red grids are located around the pedestrian crossing at the mid island and on the pedestrian crossing in the east. This is due to larger groups of pedestrians gathering and waiting for the green lights in those locations. For motorised traffic there are no red square and so no critical TTC scores. A more critical examination of the red grids on the roads themselves is possible. Upon analysis of the video recordings, it can be observed that the red grids are linked to scenarios in which motorised traffic is stationary in a congestion while vulnerable road users (VRUs) receive a green phase and move through the stationary motorised traffic. When examining VRU-VRU and motorised-motorised traffic separately, higher (safer-green) values are observable.

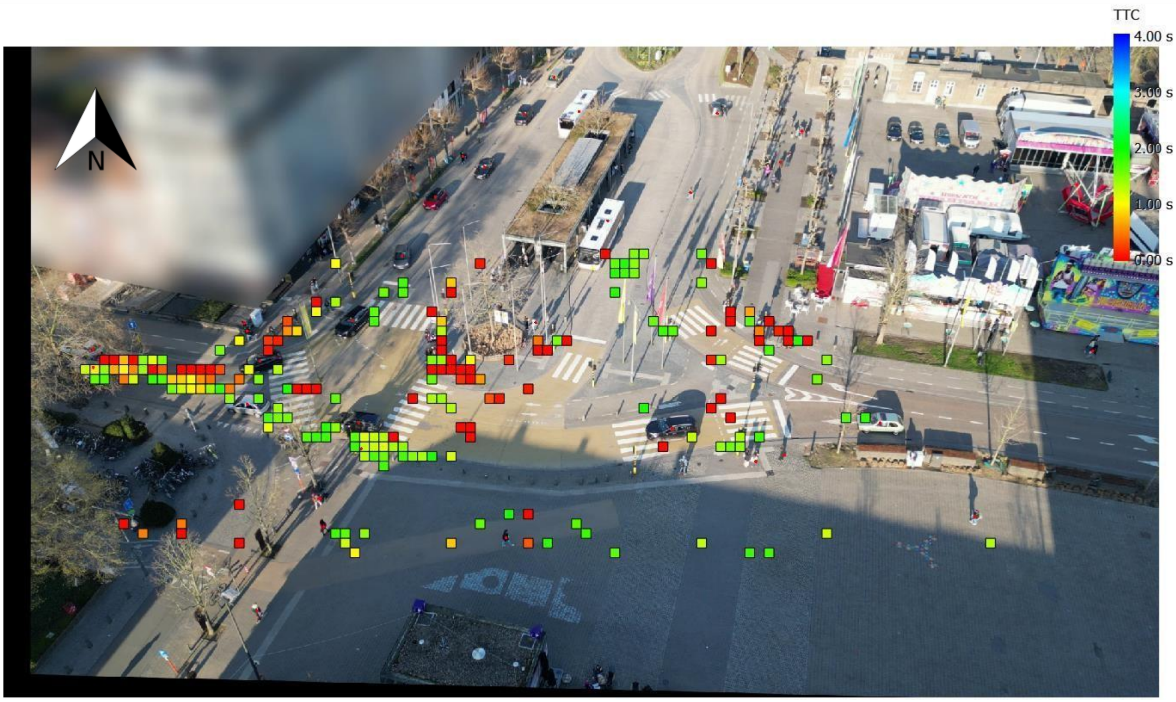


FIGURE 16: Conflict grid map TTC Dusart (DFS and own edit, 2024)

5.1.7. Dusart TTC graphs analysed

This chapter will only discuss a few relevant graphs and tables. Additional graphs and tables can be found in the enclosure chapter for further information.

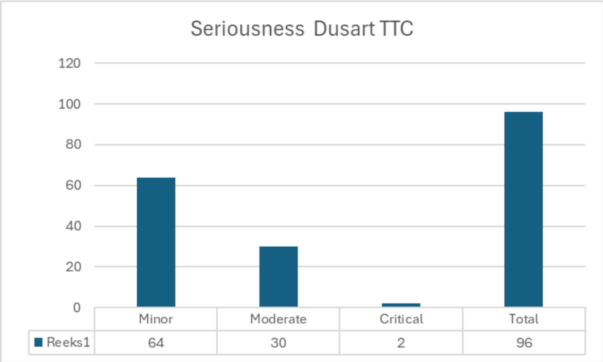


FIGURE 17: Seriousness Dusart TTC (Own edit, 2024)

The above graph, Seriousness Dusart TTC (Own edit, 2024), shows the seriousness of potential accidents at Dusart square based on the TTC indicator. Three major categories were identified: minor, moderate and critical. These categories were established based on the probability score and the safety indicator (severity score). Category minor is determined from a Delta V score of above 16, moderate is when the Delta V score is above 64 or has a safety indicator of 2 or above, and everything above those values is categorised as critical. The majority of incidents are minor conflicts (64), with 30 classified as moderate and 2 as critical. Further analysis of minor, moderate and critical conflicts can be found in the graphs below (FIGURE 18: Minor (left) and Moderate (right) accidents with type of road user Dusart TTC (Own edit, 2024). Pedestrians-bicycle accidents account for the majority of minor accidents (46%), followed by motorised-motorised conflicts (22%) and bicycle-bicycle accidents (22%). In terms of moderate conflicts, 30% of them involve motorised-motorised traffic. Moderate accidents occur between pedestrians and motorised traffic (27%). The latter refers to pedestrians waiting at crossings who come close to motorised traffic but are not in danger. The conflicts between vulnerable road users (23% bike-bike, 13% ped- bike) are the most important for the paper. During a green light cycle, traffic is separated between VRUs and motorised vehicles. The TTC indicator displays a higher number of motorised traffic conflicts compared to the PET indicator. A critical conflict happened between two motorised vehicles and is shown on the picture (FIGURE 15: Critical conflict point TTC Dusart (DFS and own edit, 2024)) under the chapter Proximal indicator TTC.

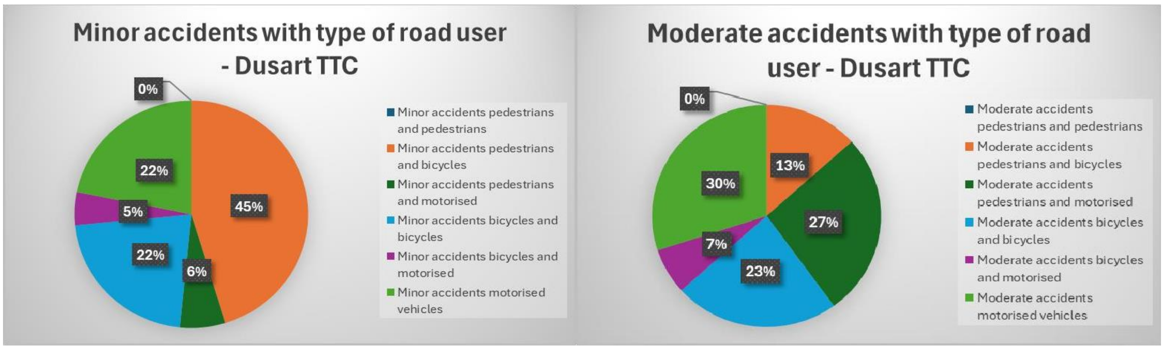


FIGURE 18: Minor (left) and Moderate (right) accidents with type of road user Dusart TTC (Own edit, 2024)

Out of the three types of conflicts observed, 57% were moderate crossing conflicts, 43% were moderate lane-changing conflicts, and none were moderate rear-end conflicts. During moderate crossing conflicts, both VRU-VRU and VRU-motorised vehicles were represented equally at 35%. The terminology of the categories is provided by the software, but does not always describe the situation correctly. Therefore, some of the (potential) conflicts are described. The VRU-motorised crossing conflict is the most concerning as it involves a vulnerable road user who is prioritised following the STOP-principle. The highest moderate seriousness score in this category was registered between a pedestrian and a bus. Examining this conflict, a bus was stationary at a red light behind the white stopping line while a pedestrian crossed nearby. Neither party was in danger. The video recordings demonstrate that the bounding boxes around the vehicles, which determine the TTC and PET, are not consistently positioned at the correct location. This may result in higher seriousness values than would be observed in real life, which could contribute to the observed categorisation of seriousness. Another potential explanation is that the Delta V value is elevated due to the mass difference between a VRU and a motorised vehicle. Other examples fitting in this VRU-motorised conflict category were VRUs who crossed the intersection right after the motorised vehicle passed. It tends to happen that motorised traffic is still on the intersection and has to clear it while VRU are already using the green phase. The potential conflicts are all located around the start of the pedestrian crossing where VRUs are waiting for the light to turn green.

VRU-VRU accounted for 38% of moderate lane-changing conflicts. The most severe incident involved two bicycles crossing diagonally in close proximity. The percentages of the different conflict types are more similar for the TTC indicator than for the PET indicator. Although diagonal crossing is not utilized that often on the intersection the crossing and lane-changing conflicts between VRU-VRU are relatively high. It indicates that when more diagonal crossings occur the percentages can increase accordingly. At the moment most diagonal crossings are happening on the southern square below the intersection, see figure trajectory lines (FIGURE 13: Trajectory map Dusart (DFS and own edit, 2024)). When measures are taken to promote green traffic light cycle on the intersection itself, by e.g. informing or singal indications, those trajectories can move from the southern square towards the intersection itself.

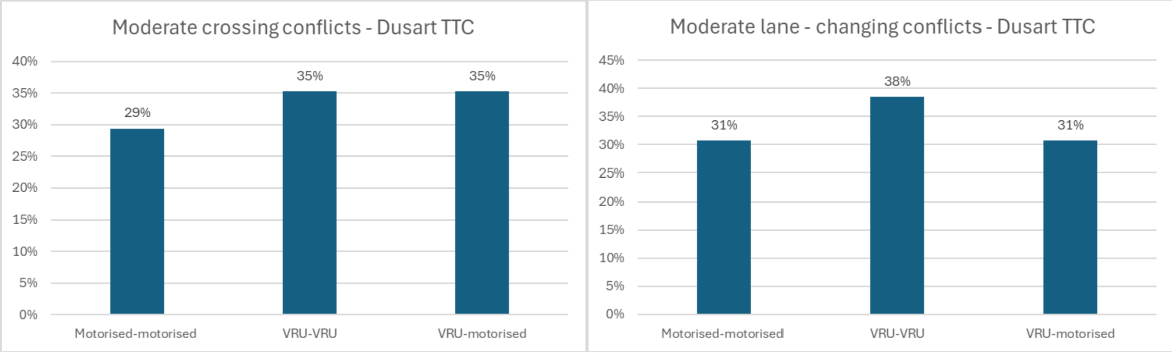


FIGURE 19: Moderate crossing (left) and Moderate lane-changing (right) conflict (Own edit, 2024)

5.1.8. The proximal indicator PET

The PET data collected from Dusart Square indicates a moderate conflict between a car (ID1738) and a pedestrian (ID1748), which was registered as a lane-changing conflict and resulted in the highest seriousness score. The typology of this conflict categorisation is not correct but rather two road users moving closely to each other. The pedestrian crossed the road soon after the car drove past, and although there was no collision, the two road users came close to each other.

FIGURE 20: Moderate conflict point PET Dusat (Own edit, 2024)

5.1.9. Conflict points PET

The threshold value for PET is also between 2s-0s, with 0s indicating a conflict and values above 2s indicating safety. Unlike TTC, PET does not have a separation threshold. This is why there are more orange grids on the map in comparison to TTC (FIGURE 15: Critical conflict point TTC Dusart (DFS and own edit, 2024)). The red grids on the crossing indicate potential conflicts between VRUs and motorised traffic. Upon examination of the footage, it can be observed that VRUs are crossing the road during the green phase, while motorised traffic has not yet cleared the intersection. The other red grids are located at waiting places for pedestrian crossings, including the crossing in the west, mid island (bus stop), and the east crossing. Pedestrians standing close to each other do not pose a threat to each other. The literature often mentions an increase in collisions between vulnerable road users (VRUs) during green traffic light cycles. The PET indicator map (FIGURE 21: Conflict grid map PET Dusart (DFS and own edit, 2024)) confirms that both road users come into close proximity. The next chapter (Dusart PET graphs analysed) will provide a more detailed analysis of this issue.

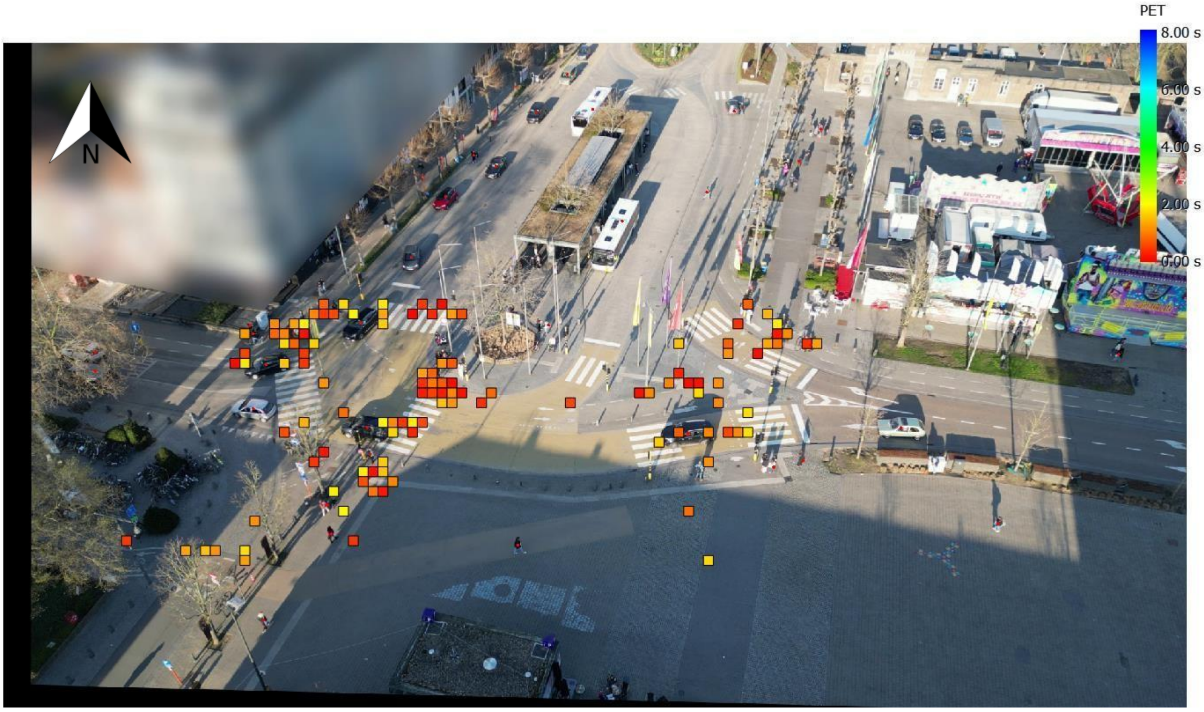


FIGURE 21: Conflict grid map PET Dusart (DFS and own edit, 2024)

The above aerial map with conflicts (FIGURE 22: Conflict grid map PET Dusart (DFS and own edit, 2024)) can be analysed in further detail. The aerial maps below (FIGURE 22: Conflict grid map PET VRU-VRU (left) and motorised-motorised (right) (DFS and own edit, 2024)) show the conflict points for the PET indicator for VRU-VRU interactions (left) and motorised-motorised interactions (right). On the left side of the figure (FIGURE 22: Conflict grid map PET VRU-VRU (left) and motorised-motorised (right) (DFS and own edit, 2024)), the conflict grid can be seen for VRU-VRU interactions. On the west side of VRU aerial map, it is evident that conflict points only occur at the waiting areas for vulnerable road users (VRUs) to cross intersections, rather than on the intersections themselves. In contrast, on the east side, where more diagonal crossing is applied (based on the trajectory map, FIGURE 13: Trajectory map Dusart (DFS and own edit, 2024)), potential conflict points between VRU-VRUs occur on the intersections themselves. This may indicate that the application of diagonal crossing in other parts of the intersection will result in the emergence of additional red grids on the intersection itself. On the right motorised-motorised aerial map, potential conflict points for motorised-motorised traffic are indicated. A visible contrast is observed between the two aerial maps, whereby there is only one red grid visible for motorised-motorised traffic.

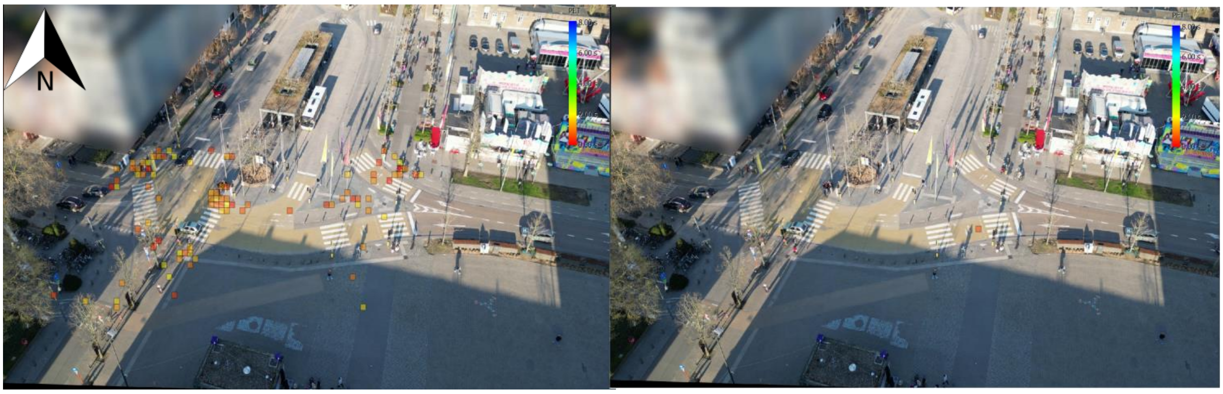


FIGURE 22: Conflict grid map PET VRU-VRU (left) and motorised-motorised (right) (DFS and own edit, 2024)

5.1.10. Dusart PET graphs analysed

This chapter will only discuss a few relevant graphs and tables. Additional graphs and tables can be found in the enclosure chapter for further information.

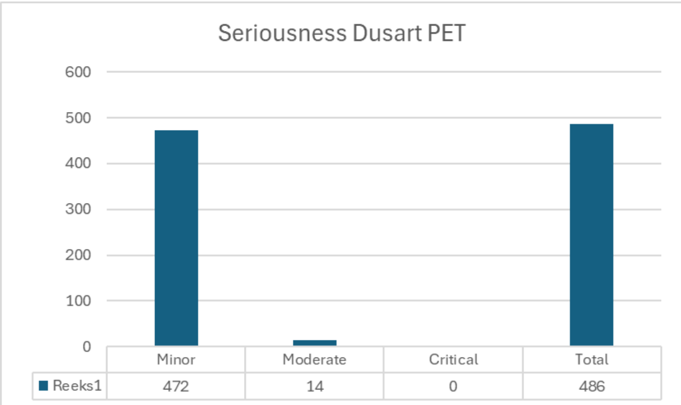


FIGURE 23: Seriousness Dusart PET (Own edit, 2024)

The above graph, Seriousness Dusart PET (Own edit, 2024), shows the seriousness of potential accidents at Dusart square based on the PET indicator. The majority of incidents are minor conflicts (472), with 14 classified as moderate and none as critical. Further analysisof minor and moderate conflicts can be found in the graphs below (FIGURE 24: Minor (left) and Moderate (right) accidents with type of roads uer PET (Own edit, 2024). Pedestrian-pedestrian accidents account for the majority of minor accidents (41%), followed by motorised- motorised conflicts (36%) and pedestrian-bicycle accidents (16%). In terms of moderate conflicts, 50% of them involve pedestrians and bicycles, as was also indicated on the conflict point map in the previous chapter, Conflict points PET. Moderate accidents occur between pedestrians and motorised traffic (22%). The latter refers to pedestrians waiting at crossings who come close to motorised traffic but are not in danger. The conflicts between vulnerable road users (50% ped-bike, 14% bike- bike and 14% ped-ped) are the most important for the paper. During a green light cycle, traffic is separated between VRUs and motorised vehicles. According to the literature, this increases safety, but also leads to more conflicts between VRUs. The percentage of conflicts is higher for VRU-VRU interactions.

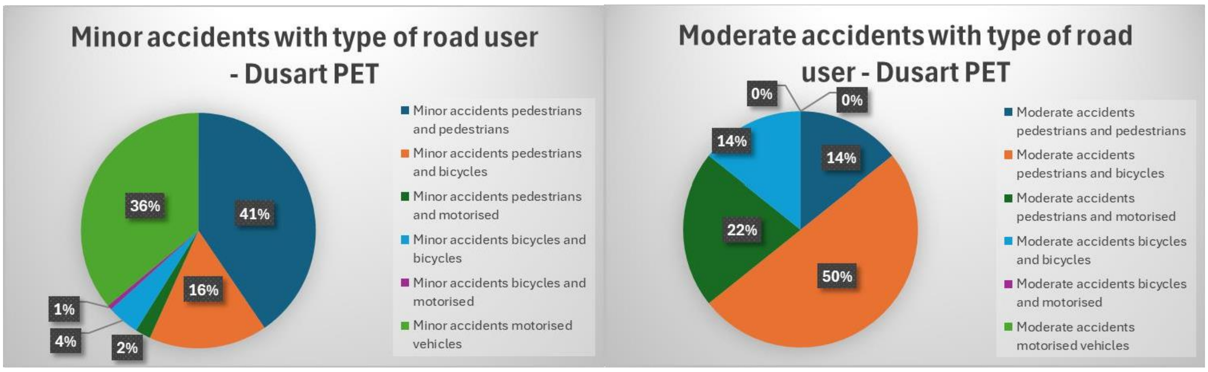


FIGURE 24: Minor (left) and Moderate (right) accidents with type of roads uer PET (Own edit, 2024)

Examining the types of moderate conflicts, 79% involve crossing while 21% involve lane-changing. Of those involved in crossing conflicts, 82% are vulnerable road users (VRU-VRU), while for lane-changing conflicts, this percentage is 67%. Lane-changing conflicts are categorized by the software but perhaps not the right terminology for conflicts between VRU-VRU. Based on the footage, these interactions are rather VRU-VRUs moving or passing each other in close proximity. The PET indicator for Dusart confirms the literature that a high percentage of conflicts occur between vulnerable road users, such as pedestrians and cyclists. This is already the case for VRUs crossing the road by the traditional way and not by diagonal crossing. It may suggest that when diagonal crossing is more utilised on the intersection these numbers may increase accordingly.

	#	Total	%
Crossing conflicts	11	14	79%
Lane-changing conflict	3	14	21%

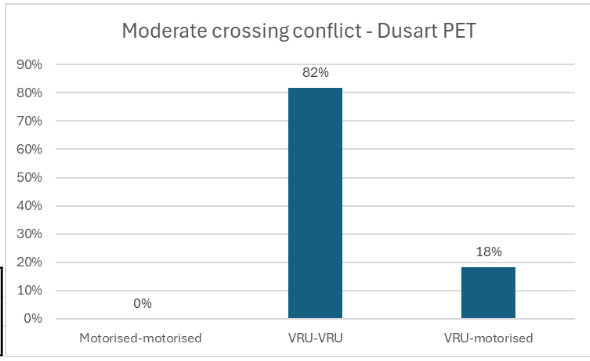


FIGURE 25: Percentage of type of conflict Dusart PET & moderate crossing conflict with type of road user (Own edit, 2024)

5.2. Location 2: Sint-Truidersteenweg and Luikersteenweg

5.2.1. Modal split

The following graph shows the modal split for the second location over a brief 30-minute period during the morning peak. The results presented below are therefore specific to the time of investigation and not generalizable to the entire day. At the junction of Sint-Truidersteenweg and Luikersteenweg, cars are the most common means of transport (during the recording time), accounting for 47% of the total. Bicycles and pedestrians follow with 28% and 17% respectively. Heavy and medium vehicles are the least used means of transport. The area is home to a school, bars, restaurants and offices. It's also an important access and exit road from the south of the city to the outskirts of Hasselt, towards Alken and Sint-Truiden. The distribution of traffic is therefore logical. It is important to note that the modal split was established using entry and exit gates. It is possible that some registered road users may be misidentified, which could result in minor discrepancies in the data. However, the overal differences between categories will remain consistent.

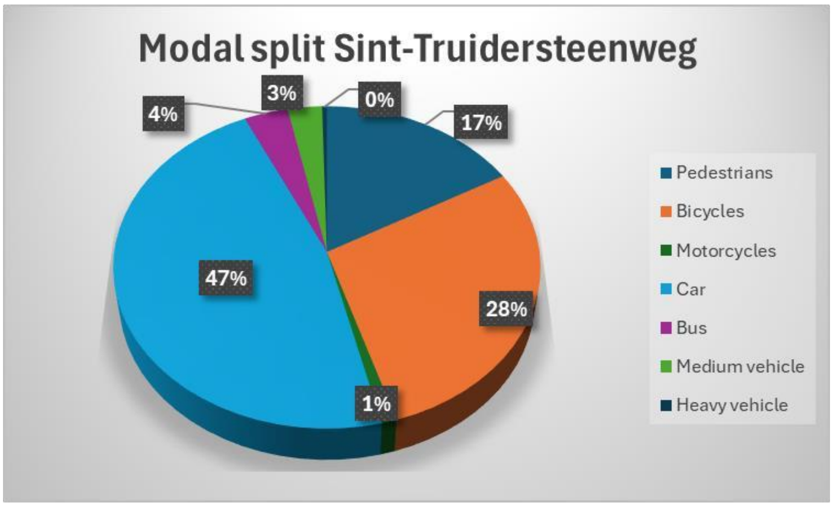


FIGURE 26: Modal split Sint-Truidersteenweg (Own edit, 2024)

5.2.2. Origin and destination

5.2.2.1 Vulnerable road users

A lot of traffic movements are happening on the aerial map below. This aerial picture shows the movements of VRU. That's is why traffic is going into streets where only one-directions is allowed. One-way traffic is mandatory for motorised traffic, not for the VRU. The recording was made in the morning. Many students were travelling from the south to either east 1 (52%, blue line) or north (33%, blue line) to their schools. The offices in East 1 attract many VRUs from the north (42%, orange line) and the west (40%, green line). East 2 contains residential areas. VRUs coming from East 2 mainly go to the city centre in the north (50%, purple line). The south, in the direction of Alken and Sint-Truiden, attracts 35% of VRU from the north (orange line) and 43% (red line) from east 1. Overall, the distribution of traffic is logical, given the type of attractions in the surrounding areas. In the table below (

TABLE 9: O/D Matrix VRU Sint-Truidersteenweg per hour (Own edit, 2024**)**) the exact number of VRUs per hour are written.

TABLE 9: O/D Matrix VRU Sint-Truidersteenweg per hour (Own edit, 2024)

O/D Matrix VRU Sint-Truidersteenweg	Exit Gate 30 (tag: East 1)	Exit Gate 32 (tag: East 2)	Exit Gate 34 (tag: South)	Exit Gate 36 (tag: West)	Exit Gate 38 (tag: North)
Entry Gate 29 (tag: East 1)	0	6	12	4	6
Entry Gate 31 (tag: East 2)	8	0	6	28	42
Entry Gate 33 (tag: South)	174	32	0	16	110
Entry Gate 35 (tag: West)	126	66	14	0	106
Entry Gate 37 (tag: North)	22	4	18	8	0

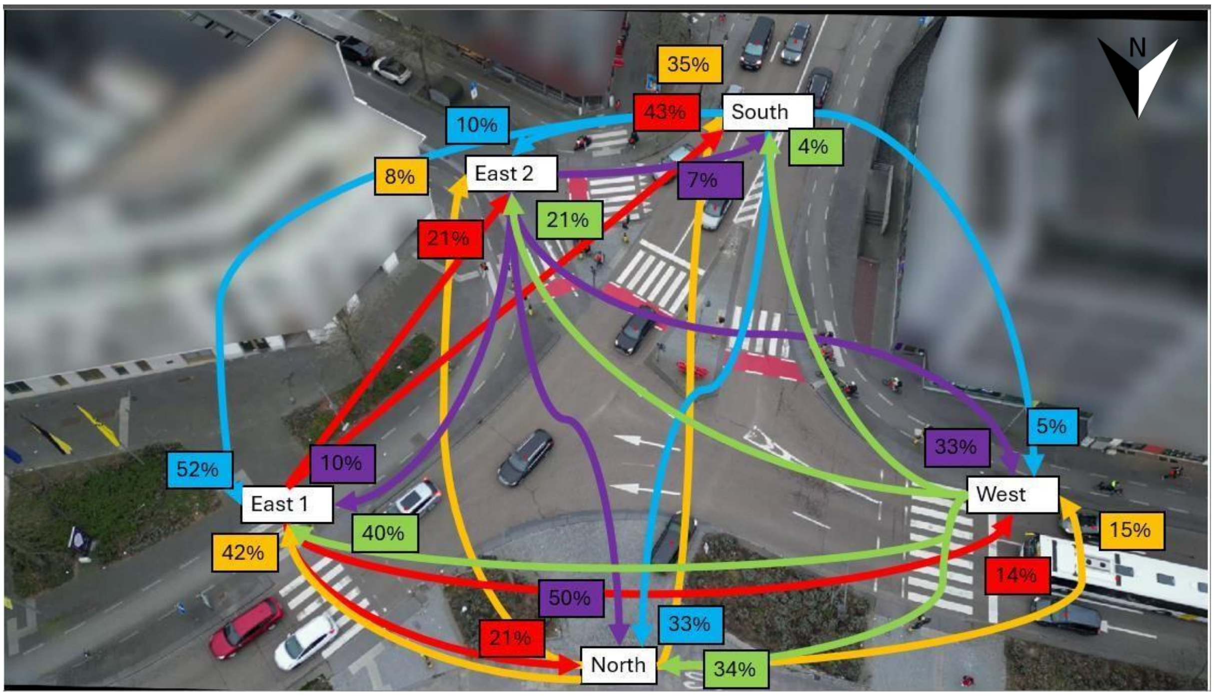


Figure: O/D Matrix VRU aerial map Sint-Truidersteenweg Source: Own edit, 2024
Legend: orange lines= north, red lines= east 1, purple lines= east 2, blue lines= south and green lines= west.

5.2.2.2 Motorised vehicles

Because of the mandatory one-way traffic for motorised traffic other origin destination lines are visible. Most motorised traffic is attracted to East 1. From south to east 1 (88%, blue line); from west to east 1 (57%, green line). This is a logical number, because during the morning rush hour most traffic is attracted to the inner circle of Hasselt for all kinds of activities. This is why the number of trips to the east 2 (residential area) and to the south are lower in comparison. Furthermore, the inner ring of Hasselt is oriented in a single direction and follows a counterclockwise trajectory (from the perspective of the drone cameras, from west to east). Notable numbers are 2% and 1% going to the north, which is a one-way street. Looking at the footage, smaller motorcycles were going the wrong way.

TABLE 10: O/D Matrix Motorised traffic Sint-Truidersteenweg (Own edit, 2024)

O/D Matrix Motorised Sint-Truidersteenweg	Exit Gate 30 (tag: East 1)	Exit Gate 32 (tag: East 2)	Exit Gate 34 (tag: South)	Exit Gate 36 (tag: West)	Exit Gate 38 (tag: North)
Entry Gate 29 (tag: East 1)	0	0	0	0	0
Entry Gate 31 (tag: East 2)	0	0	0	2	0
Entry Gate 33 (tag: South)	638	76	0	0	12
Entry Gate 35 (tag: West)	452	134	200	0	4
Entry Gate 37 (tag: North)	4	2	50	0	2

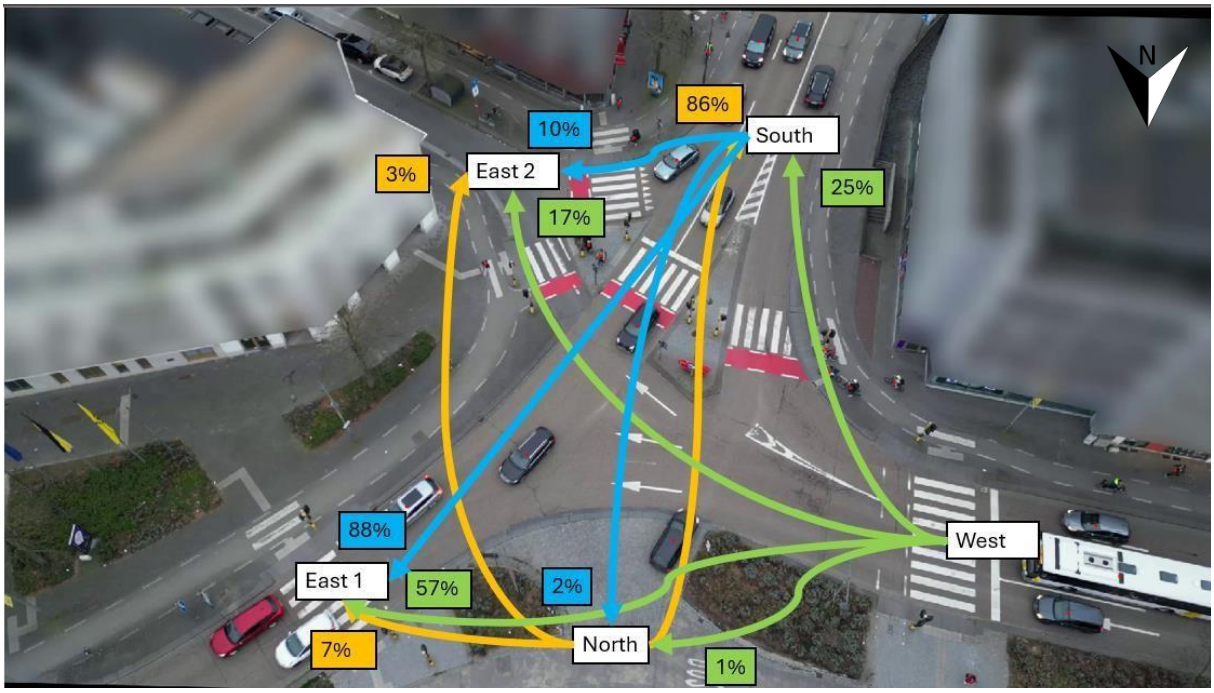


FIGURE 27: OD/ Matrix Motorised traffic aerial map Sint-Truidersteenweg (Own edit, 2024)

Legend: Legend: orange lines= north, red lines= east 1, purple lines= east 2, blue lines= south and green lines= west.

5.2.3. Occuring speeds

The speeds at which motorised vehicles travel are as follows. The average speed recorded on intersection of Sint-Truidersteenweg and Luikersteenweg was 21km/h. The maximum speed was 67,3km/h. This is higher than the speed limit at the junction, which is 50 km/h. The V85, or what 85% of the drivers drive, is 16,3km/h. This is lower than the permitted speed.

The map below (FIGURE 28: Maximum speeds Sint-Truidersteenweg (DFS and own edit, 2024)) visualises the maximum speeds, with red indicating speeds closest to 70km/h and green indicating lower speeds. It is pertinent to mention that the maximum speed limit was exceeded. Speeds in excess of the permitted limit were observed on the southbound approach from the bridge. This is a noteworthy observation, as while driving downhill does result in increased speed, the presence of traffic lights would suggest that the traffic slows down in anticipation of a red light. The motorised traffic exhibited speeds between 35 and 50 km/h (green to yellow colours).

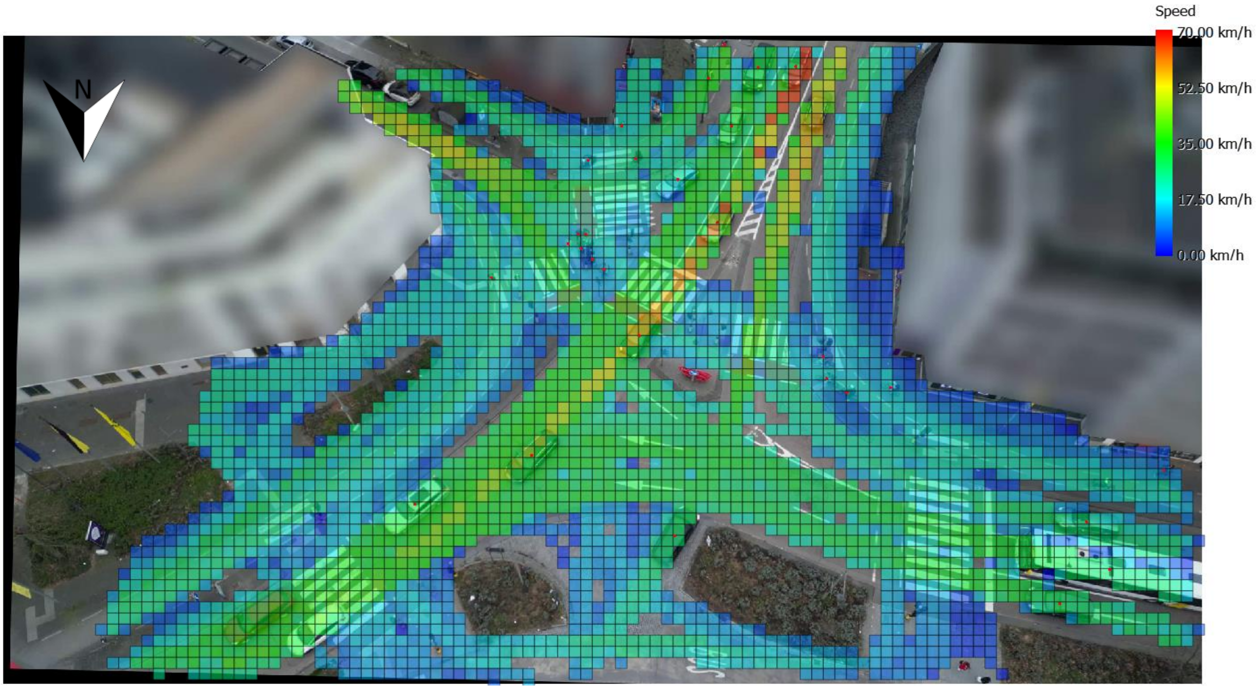


FIGURE 28: Maximum speeds Sint-Truidersteenweg (DFS and own edit, 2024)

The map below (FIGURE 29: Average speeds Sint-Truidersteenweg (DFS and own edit, 2024)) displays average speeds, using the same colour scale as the previous map. The relatively low average speeds of motorised traffic, is due to the necessity of stopping at traffic signals. The speeds are a higher for motorised traffic, in comparison to lower speeds in areas with vulnerable road users such as pedestrians and cyclists, including walkways, and the square in the north.

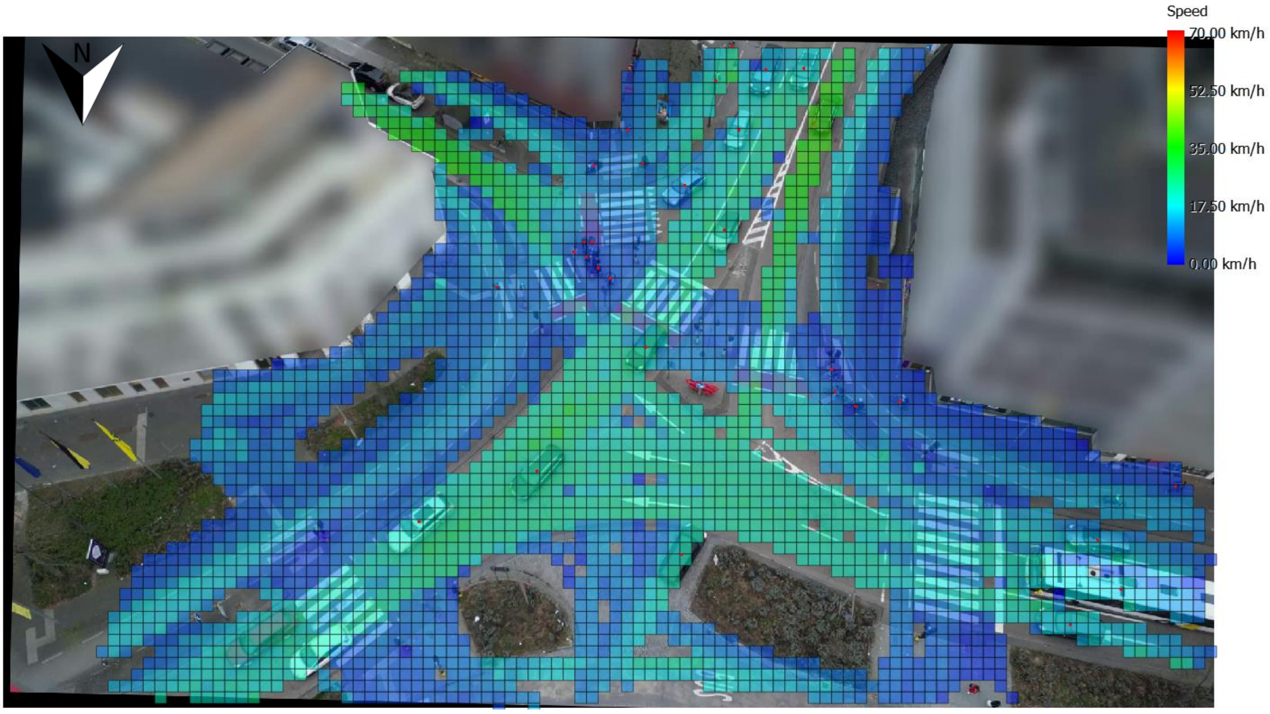


FIGURE 29: Average speeds Sint-Truidersteenweg (DFS and own edit, 2024)

5.2.4. Trajectory of the road users

The map illustrates the trajectories of road users on the intersection of Sint-Truidersteenweg and Luikersteenweg during the recorded period. Vulnerable road users, represented in blue, include pedestrians and cyclists. Motorised traffic, represented by purple lines, includes cars, buses, motorcycles, medium vehicles, and heavy vehicles. Motorised vehicles are restricted to designated roads. Vulnerable road users can be found on walkways and cycle lanes. The intersection of Sint-Truidersteenweg and Luikersteenweg has a green traffic light cycle and so diagonal crossing is allowed for VRUs. Their movements are happening on the pedestrian crossings and designated paths. Nonetheless, some blue lines are also visible in the middle of the aerial map in the north. There is no cycling path or pedestrian crossing and it can be derived that some VRUs used the option of diagonal crossing. Further investigation of the crossings reveals additional details. Although the designated paths are followed, blue lines are also visible in close proximity to the crossings. This indicates that vulnerable road users (VRUs) may utilise shortcuts to reduce the distance travelled or maintain their speed, and may walk or drive alongside the crossing rather than following the designated path until they reach the white markings.

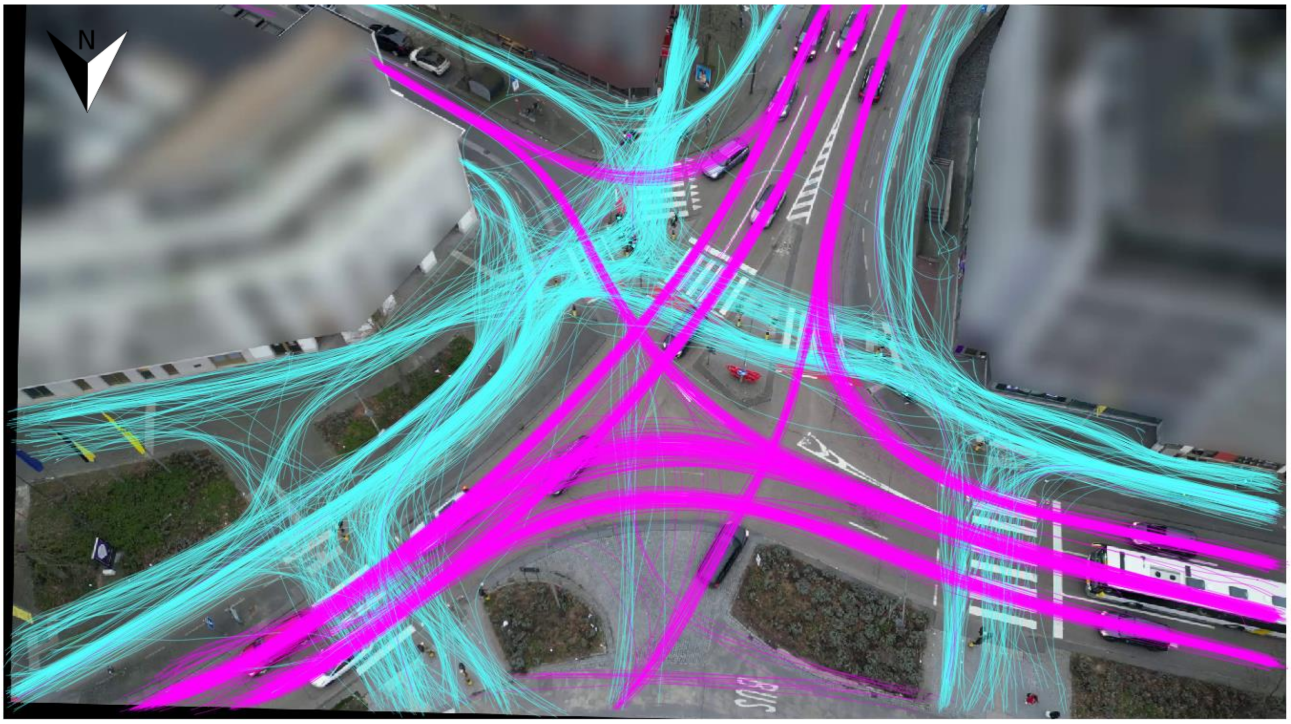


FIGURE 30: Trajectory map Sint-Truidersteenweg (DFS and own edit, 2024)

The trajectory map (FIGURE 30: Trajectory map Sint-Truidersteenweg (DFS and own edit, 2024)) and the VRU O/D matrix (FIGURE 27: OD/ Matrix Motorised traffic aerial map Sint-Truidersteenweg (Own edit, 2024)) can be combined, as shown below (FIGURE 31: Trajectory map with O/D matrix Sint-Truidersteenweg (DFS and own edit, 2024)). As previously stated, a considerable number of students were travelling from the southern region to either east 1 (52%, represented by the blue line) or north (33%, represented by the blue line) in order to attend their educational institutions. The trajectory lines, displayed as a top layer, demonstrate that the designated crossings are utilized by the majority of travelers on this route. The offices in East 1 attract the west (40%, green line), with the route used for this being the crossings in the south and not the path in the north. Consequently, there is no usage of diagonally crossing the intersection from the west directly towards East 1. VRUs coming from East 2 (residential area) mainly go to the city centre in the north (50%, purple line). It is visible that a proportion of these pedestrians utilise a direct diagonal route to traverse the distance between East 2 and the north, while the majority of them utilise the conventional crossing points.

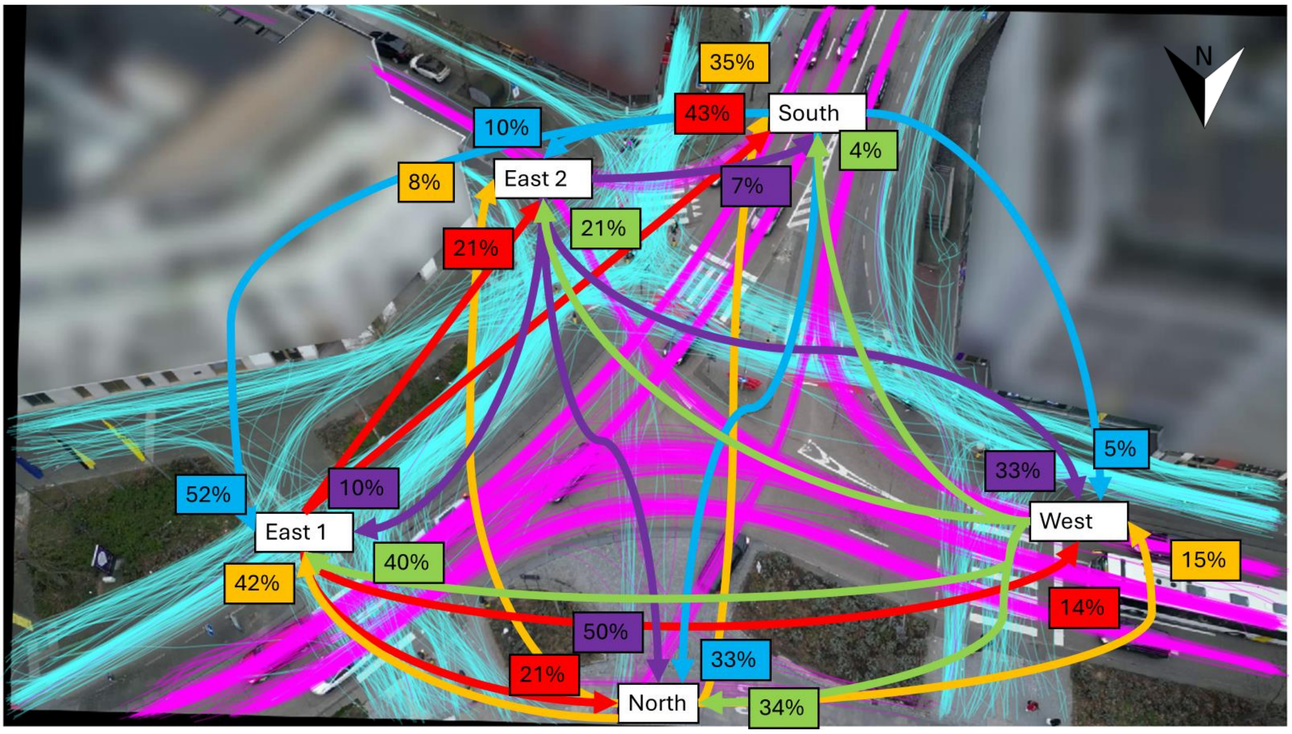


FIGURE 31: Trajectory map with O/D matrix Sint-Truidersteenweg (DFS and own edit, 2024)

5.2.5. Proximal indicator TTC

The TTC data recorded a critical situation at the intersection of Sint-Truidersteenweg and Luikersteenweg. The highest severity score was for a lane- changing conflict between a bus (ID257) and a car (ID286). The accompanying picture shows that the car and bus were not in a dangerous situation and maintained a safe distance.

FIGURE 32: Critical conflict point TTC Sint-Truidersteenweg (DFS and own edit, 2024)

5.2.6. Conflict points TTC

The previous chapter, Proximal indicator TTC, analysed the highest seriousness score, which is based on the probability of a conflict and the severity, for the TTC parameter, which was recorded as a moderate lane-changing conflict. The map below (FIGURE 33: Conflict grid map TTC Sint-Truidersteenweg (DFS and own edit, 2024)) shows a grid map based on the TTC indicator. The legend is constructed using threshold values from the literature and is as follows: a time of 0s-1s is a critical TTC score (red), between 1s-1.9s is considered moderate (yellow), and >2s indicates a non-dangerous situation (green to blue). The data indicate that the areas with the highest concentration of red grids are located around the pedestrian crossing in the west. Below, three aerial maps can be found. The first image shows conflict points for VRUs and motorised traffic. This does not imply a conflict between VRUs and motorised traffic. Consequently, further aerial maps must be produced in order to gain a more detailed understanding of this matter. The remaining two aerial maps illustrate motorised-motorised conflicts and

VRU-VRU conflicts, respectively. A more detailed analysis can be conducted by differentiating between the types of road users. A greater concentration of green squares is idenitified in the waiting areas for VRUs in the east, while a higher concentration of red squares is visible in the west. The hypothesis that the higher concentration of green and red squares around the pedestrian crossings' waiting areas is due to larger groups of pedestrians gathering and waiting for the green lights; is confirmed by the analysis of the video footage. A review of the red squares in the footage reveals that some traffic is passing closely, while other traffic is waiting to make a turn at the intersection. This is consistent with the findings presented in the previous chapter, Proximal indicator TTC.

FIGURE 33: Conflict grid map TTC Sint-Truidersteenweg (DFS and own edit, 2024)

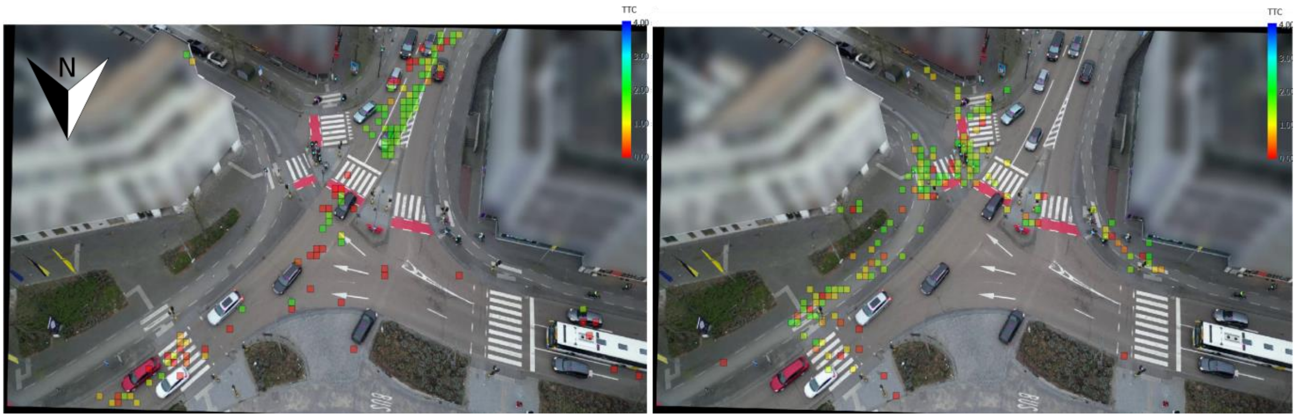


FIGURE 34: Conflict grid map TTC Sint-Truidersteenweg motorised traffic (left) and VRU (right) (DFS and own edit, 2024)

5.2.7. Sint-Truidersteenweg TTC graphs analysed

This chapter will only discuss a few relevant graphs and tables. Additional graphs and tables can be found in the enclosure chapter for further information.

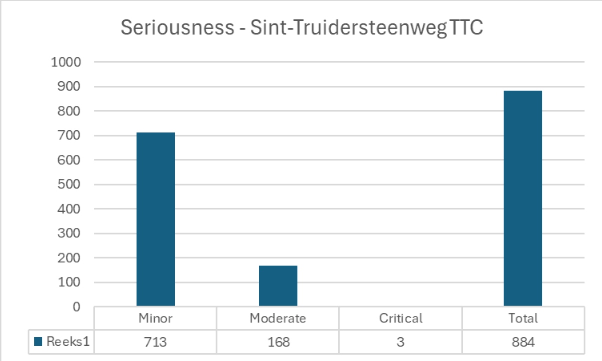


FIGURE 35: Seriousness Sint-Truidersteenweg TTC (Own edit, 2024)

The above graph, Seriousness Sint-Truidersteenweg TTC (Own edit, 2024), illustrates the potential severity of accidents at the intersection of Sint-Truidersteenweg and Luikersteenweg, as indicated by the TTC indicator. Three principal categories were identified: minor, moderate, and critical. The categories were established on the basis of the probability score and the safety indicator (severity score). The category of "minor" is defined by a Delta V score of above 16. The category of "moderate" is defined by a Delta V score of above 64 or a safety indicator of 2 or above. Finally, the category of "critical" is defined by a Delta V score of above those values. The majority of incidents were classified as minor conflicts (713), with 168 classified as moderate and 3 classified as critical. Further analysis of minor, moderate and critical conflicts can be found in the graphs below (FIGURE 36: minor accidents (left) and moderate accidents (right) with type of road user Sint-Truidersteenweg TTC (Own edit, 2024). The majority of minor accidents are bicycle-bicycle accidents (47%), followed by pedestrian-bicycle accidents (22%) and bicycle-motorised conflicts (16%). With regard to moderate conflicts, it can be observed that 52% of them involve bicycle-bicycle traffic. Twenty percent of moderate accidents involve pedestrians and motorised traffic. The latter category pertains to pedestrians who are waiting at crossings and who come close to motorised traffic but are not in danger. The conflicts between vulnerable road users (52% bike-bike, 13% ped-bike) are of particular interest to this paper. During a green light cycle, traffic is separated between vulnerable road users (VRUs) and motorised vehicles. Three critical conflicts occurred between two motorised vehicles, as illustrated in the accompanying example figure (FIGURE 32: Critical conflict point TTC Sint-Truidersteenweg (DFS and own edit, 2024)) in the Proximal indicator TTC chapter.

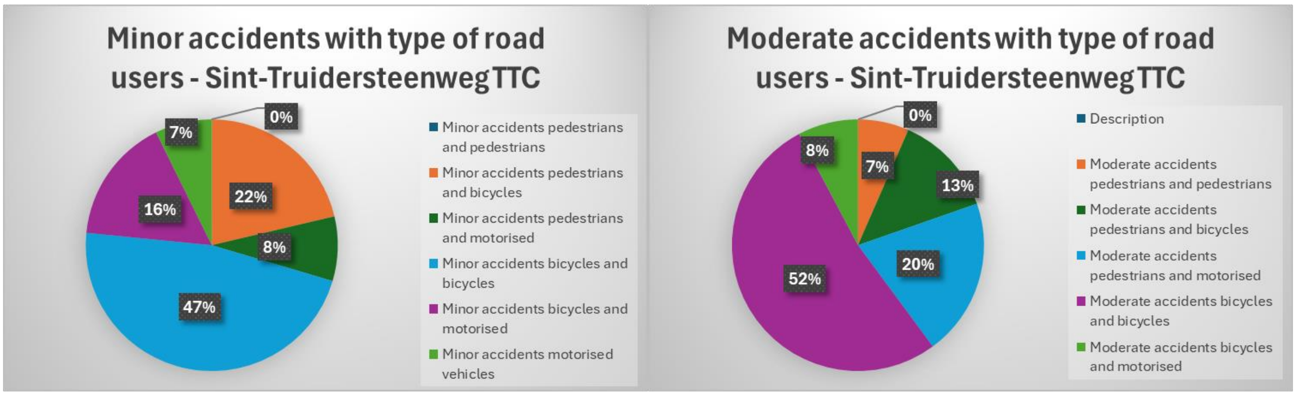


FIGURE 36: minor accidents (left) and moderate accidents (right) with type of road user Sint-Truidersteenweg TTC (Own edit, 2024)

A total of 50% of the observed conflicts were classified as moderate lane-changing conflicts, 43% as moderate crossing conflicts, and 7% as moderate rear-end conflicts. Three potential critical conflicts were identified as falling into the category of lane-changing conflicts. In moderate crossing conflicts, the proportion of VRUs involved in motorised traffic was 54%, while the proportion of VRU-VRUs was 46%. The categorisation of the incidents is determined by the software, although this does not always accurately reflect the circumstances. It is therefore necessary to describe some of the potential conflicts. The VRU-motorised crossing conflict is of particular concern, as it involves a vulnerable road user who is prioritised in accordance with the STOP principle. The highest moderate seriousness score in this category was observed in a conflict between a pedestrian and a bus. Upon examination of this conflict, it was observed that the bus was in motion while the pedestrian was positioned at the pedestrian crossing, awaiting the green light. Neither party was in imminent danger. The video recordings demonstrate that the bounding boxes around the bus, which determine the TTC and PET, are not consistently positioned at the correct location. This may result in higher seriousness values than would be observed in real life, which could contribute to the observed categorisation of seriousness. An alternative hypothesis is that the Delta V value is elevated due to the mass difference between a VRU and a motorised vehicle.

On the Dusart Square, it is observed that motorised traffic is still present at the intersection and must clear it while VRU are already using the green phase. In contrast, for traffic approaching the intersection from the western arm and south arm of the intersection of Sint-Truidersteenweg and Luikersteenweg, this was not the case. Once the VRUs commenced crossing the intersection, the motorised traffic was cleared. For the eastbound arm, motorised traffic accumulated, and pedestrians commenced crossing the road while congestion downstream prevented the clearance for the pedestrian crossing at that location. The proportion of moderate lane-changing conflicts attributable to VRU-motorised traffic was 81%. The most severe potential incident involved a bicycle and a car passing in close proximity. The percentages of the different conflict types are more similar for the TTC indicator than for the PET indicator.

Although diagonal crossing is not a common occurrence at this intersection, the number of conflicts between VRU-VRU crossing at this location is relatively high. Conversely, the number of conflicts between VRU-VRU in relation to lane changing is relatively low. At the locations where diagonal trajectories for vulnerable road users (VRUs) were observed (see FIGURE 30: Trajectory map Sint-Truidersteenweg (DFS and own edit, 2024)), no potential conflicts were observed (see **FIGURE** 33: Conflict grid map TTC Sint-Truidersteenweg (DFS and own edit, 2024)). This implies that an increase in diagonal crossings at this intersection (Sint-Truidersteenweg) does not necessarily result in a proportional increase in the percentages. The implementation of measures to promote the green traffic light cycle at the intersection, such as the provision of information or signal indications, may result in an increase in the number of diagonal crossings.

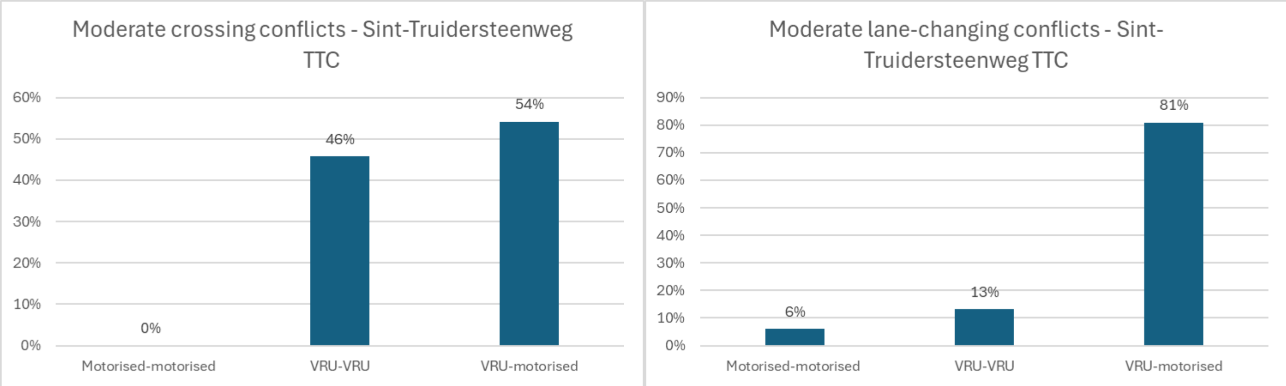


FIGURE 37: Moderate crossing conflict (left) and moderate lane-changing conflict (right) Sint-Truidersteenweg TTC (Own edit, 2024)

5.2.8. Proximal indicator PET

The highest seriousness score, as classified by the PET data of the intersection between Sint-Truidersteenweg and Luikersteenweg, was found to be a moderate situation involving a car (ID685) and a pedestrian (ID673), registered as a rear-end conflict. The typology of this conflict categorisation is not accurate; rather, it is more appropriate to describe the situation as two road users moving closely to each other. The pedestrian crossed the road shortly after the car had passed, and although there was no collision, the two road users came close to each other. The accompanying image illustrates that the vehicle and the pedestrian were not in a hazardous situation and maintained a safe distance.

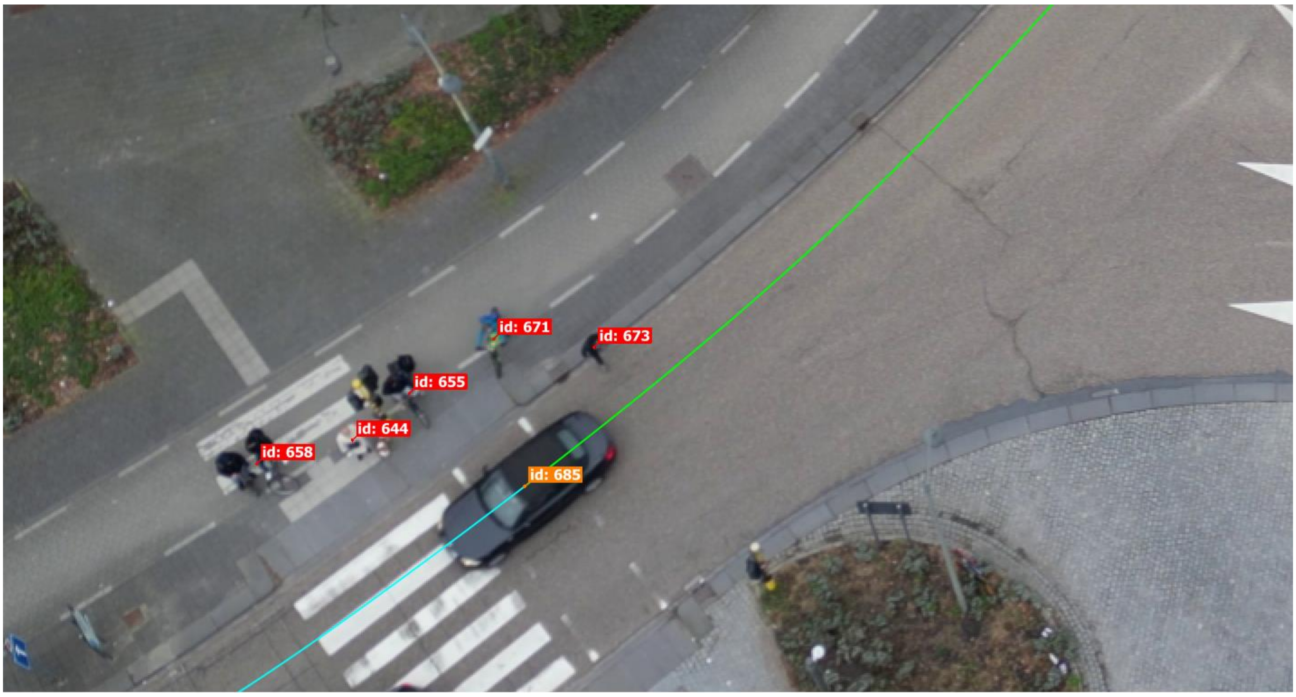


FIGURE 38: Moderate conflict point PET Sint-Truidersteenweg (Own edit, 2024)

5.2.9. Conflict points PET

The threshold value for PET is also situated between 2s and 0s, with 0s signifying a conflict and values above 2s indicating safety. In contrast to TTC, PET does not possess a separation threshold. This is the reason why there are more orange grids on the map in comparison to TTC (FIGURE 33: Conflict grid map TTC Sint-Truidersteenweg (DFS and own edit, 2024)). The same conclusion can be drawn from the PET aerial map as from the TTC aerial map. The presence of red grids on the crossing map indicates the potential for conflict between vulnerable road users (VRUs). These locations are situated at points of waiting for pedestrians crossing the road, including the crossing in the west, east 1 and east 2, with the highest concentration observed at the latter. It can be reasonably assumed that pedestrians who are in close proximity to one another do not present a threat to one another. The literature frequently cites an increase in collisions between vulnerable road users (VRUs) during green traffic light cycles. The PET indicator map (FIGURE 39: Conflict grid map PET Sint-Truidersteenweg (DFS and own edit, 2024)) confirms that both road users come into close proximity, although this does not necessarily pose a threat. The subsequent paragraph will present a more comprehensive analysis of this issue.

FIGURE 39: Conflict grid map PET Sint-Truidersteenweg (DFS and own edit, 2024)

FIGURE 40: Conflict grid map PET motorised-motorised (left) and VRU-VRU (right) (DFS and own edit, 2024)

The aerial maps above (Conflict grid map PET motorised-motorised (left) and VRU-VRU (right) (DFS and own edit, 2024)) illustrate the conflict points for the PET indicator in relation to motorised-motorised interactions (left) and VRU-VRU interactions (right). On the east 2 side of the VRU-VRU aerial map, it is evident that conflict points occur at the waiting areas and crossing areas for vulnerable road users (VRUs) to cross intersections. This can be linked to the high traffic intensity and disruptive movements at the location, which can be confirmed with the trajectory map (FIGURE 30: Trajectory map Sint-Truidersteenweg (DFS and own edit, 2024)). Conversely, the other crossing facilities in the east 1 and west exhibit a comparatively lower number of potential conflict points. On the trajectory map (FIGURE 30: Trajectory map Sint-Truidersteenweg (DFS and own edit, 2024)), it can be observed that there are fewer disruptive movements, which would appear to confirm the hypothesis that there are fewer potential conflict points at east 1 and west. A clear contrast in the number of potential conflict points is evident on the motorised-motorised aerial map, with a significantly lower number of red grids observed.

5.2.10. Sint-Truidersteenweg PET graphs analysed

This chapter will only discuss a few relevant graphs and tables. Additional graphs and tables can be found in the enclosure chapter for further information.

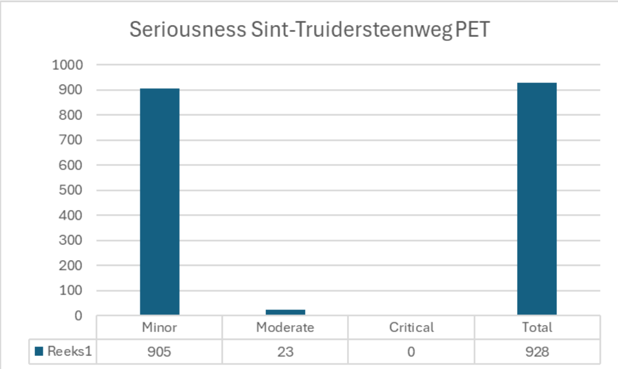


FIGURE 41: Seriousness Sint-Truidersteenweg TTC (Own edit, 2024)

The above graph, Seriousness Sint-Truidersteenweg TTC (Own edit, 2024), illustrates the potential severity of accidents at the intersection of Sint-Truidersteenweg and Luikersteenweg, as indicated by the PET indicator. The majority of incidents (905) were classified as minor conflicts, with 23 incidents classified as moderate and none classified as critical. Further analysis of minor and moderate conflicts can be found in the graphs below (FIGURE 42: Minor accidents (left) and moderate accidents (right) with type of road user Sint-Truidersteenweg PET (Own edit, 2024). The majority of minor accidents are attributed to motorised-motorised collisions (43%), followed by bicycle-bicycle conflicts (36%) and pedestrian-bicycle accidents (14%). With regard to moderate conflicts, it can be observed that 35% of them involve pedestrians and bicycles, as was also indicated on the conflict point map in the previous chapter, Conflict points PET. Moderate accidents occur between bicycles and other bicycles (30%). The conflicts between vulnerable road users (35% ped-bike, 30% bike-bike) are of particular interest to this paper. During a green light cycle, traffic is separated between VRUs and motorised vehicles. According to the literature, this increases safety, but also leads to more conflicts between VRUs.

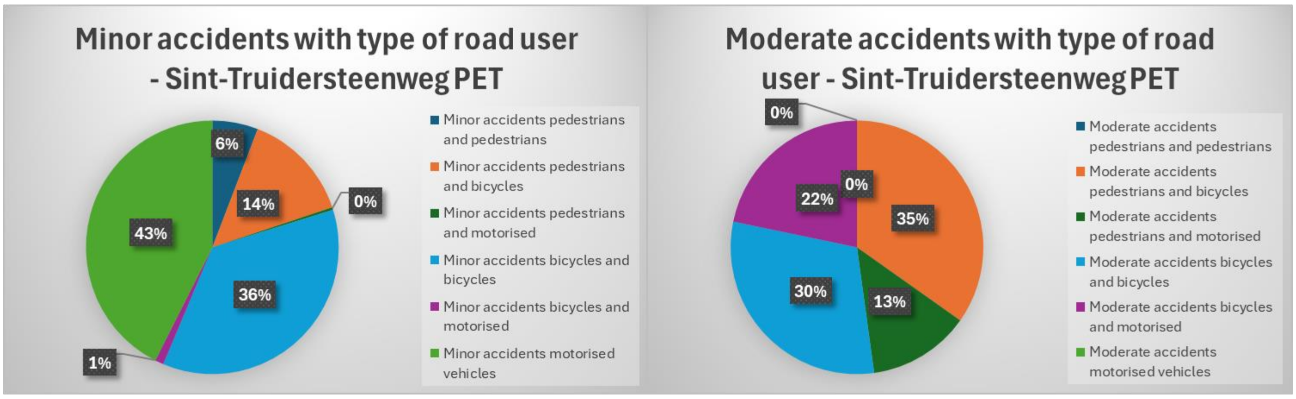


FIGURE 42: Minor accidents (left) and moderate accidents (right) with type of road user Sint-Truidersteenweg PET (Own edit, 2024)

A review of the types of moderate conflicts revealed that 70% involved crossing, while 30% involved lane-changing. In the case of crossing conflicts, 88% of those involved are vulnerable road users (VRU-VRU), while in the case of lane-changing conflicts, this percentage is 14%. The software categorises lane-changing conflicts, but this terminology may not be entirely appropriate for conflicts between vulnerable road users (VRU-VRU). The footage indicates that these interactions involve vulnerable road users (VRUs) moving or passing each other in close proximity. The PET indicator for Sint-Truidersteenweg confirms the findings of literature that a high percentage of conflicts occur between vulnerable road users, such as pedestrians and cyclists. This is already the case for VRUs crossing the road by the traditional way and not by diagonal crossing.

	#	Total	
Crossing conflicts	16	23	70%
Lane-changing conflict	7	23	30%

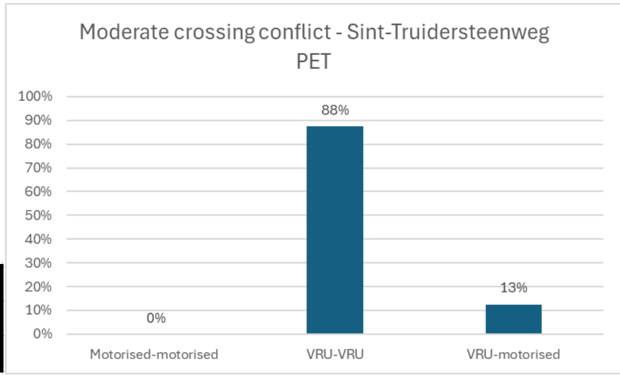


FIGURE 43: Moderate crossing conflict Sint-Truidersteenweg PET (Own edit, 2024)

5.3. Location 3: Kunstlaan & Guffenslaan

5.3.1. Modal split

The following graph illustrates the modal split for the third location over a brief 30-minute period during the evening peak. The results presented below are therefore specific to the time of investigation and not generalisable to the entire day. Pedestrians are the most common mode of transportation on intersection of Kuntslaan and Guffenslaan (during the recording time), accounting for 42% of the total. Subsequently, cars and bicycles follow, representing 38% and 14% of the total, respectively. The least utilised modes of transportation are those of heavy vehicles and motorcycles. The area is home to a number of educational institutions, cultural centres and residential areas, which collectively contribute to the logical distribution of modes of transportation observed. It is crucial to highlight that the modal split was determined through the use of entry and exit gates. It is possible that some registered road users may be misidentified, which could result in minor discrepancies in the data. Nevertheless, the overall discrepancies between categories will remain consistent.

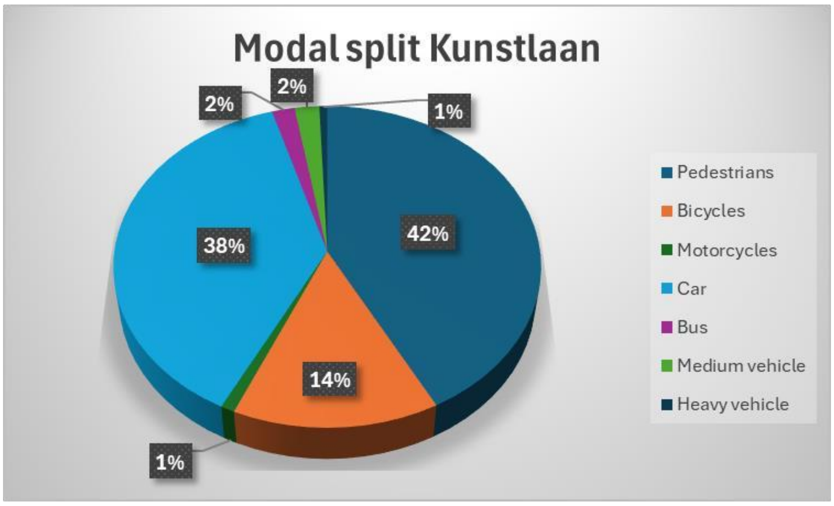


FIGURE 44: Modal split Kunstlaan (Own edit, 2024)

5.3.2. Origin and destination

5.3.2.1 Vulnerable road users

The aerial map (FIGURE 45: O/D Matrix VRU aerial map Kunstlaan (Own edit, 2024)) illustrates the origin and destination of VRU traffic at the junction of Kunstlaan and Guffenslaan during the morning rush hour. The majority of activity occurred at the school in the west, where children were arriving and leaving for extracurricular activities. As a result, the school attracted traffic from both the north (40%, purple line) and south (42%, orange line). The school is generating traffic towards the south (35%, red line) and north (52%, red line). The high school in the southeast has two entrances, one in the south and one in the east. The entrance in the south attracts more VRU students than the east entrance. The percentages are generally higher in the south. Most VRU continue their route towards the north, with 49% (orange line) coming from the south and 48% (blue line) from the east.

TABLE 11: O/D Matrix VRU Kunstlaan per hour (Own edit, 2024)

O/D Matrix VRU Kunstlaan	Exit Gate 9 (tag: East)	Exit Gate 11 (tag: North)	Exit Gate 15 (tag: South)	Exit Gate 19 (tag: School)
Entry Gate 8 (tag: East)	0	44	24	24
Entry Gate 10 (tag: North)	50	0	72	80
Entry Gate 14 (tag: South)	12	96	4	82
Entry Gate 18 (tag: School)	6	32	22	2

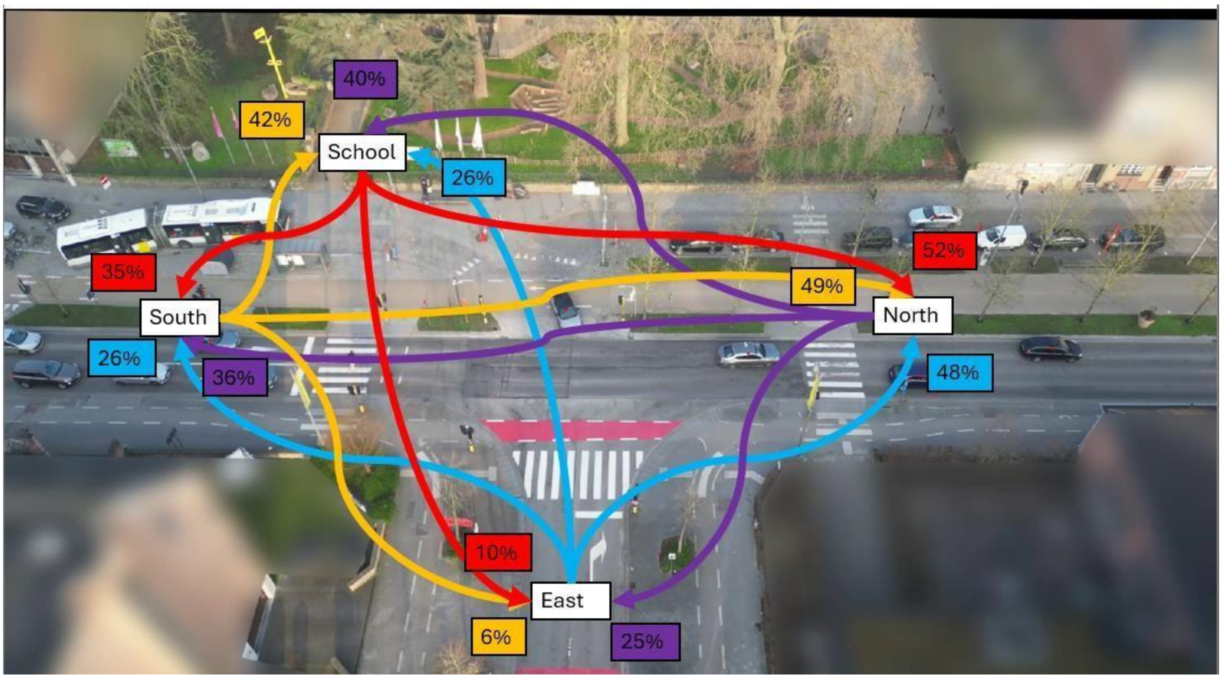


FIGURE 45: O/D Matrix VRU aerial map Kunstlaan (Own edit, 2024)
Legend: purple line= north, blue line= east, orange line= south, red line= school/west

5.3.2.2 Motorised vehicles

The origin and destination points of motorised traffic can be readily identified (FIGURE 46: O/D Matrix Motorised traffic aerial map Kunstlaan (Own edit, 2024)). The south and north routes are designated as one-way, while the east route is designated as two-way. Furthermore, a parallel road exists to the south and north routes, which permits only northbound and eastbound traffic. The majority of traffic is headed north, with 70% (orange line) originating from the south and 100% (blue line) originating from the east. It is reasonable to posit that the majority of traffic heading north from the east is logical, given that this is the only available direction. As the inner ring road of Hasselt is one-way and follows a counterclockwise route (from south to north on this aerial map), the majority of traffic is distributed from the south (see Table 1). The aforementioned traffic typically continues north on the inner ring circle. The statistic of 67% is worthy of note. The traffic in question originates from the northern parallel road and continues in a northerly direction.

TABLE 12: O/D Matrix Motorised traffic Kunstlaan (Own edit, 2024)

O/D Matrix Motorised Kunstlaan	Exit Gate 9 (tag: East)	Exit Gate 11 (tag: North)	Exit Gate 15 (tag: South)	Exit Gate 19 (tag: School)
Entry Gate 8 (tag: East)	0	102	0	0
Entry Gate 10 (tag: North)	36	74	0	0
Entry Gate 14 (tag: South)	238	568	0	0
Entry Gate 18 (tag: School)	0	0	0	0

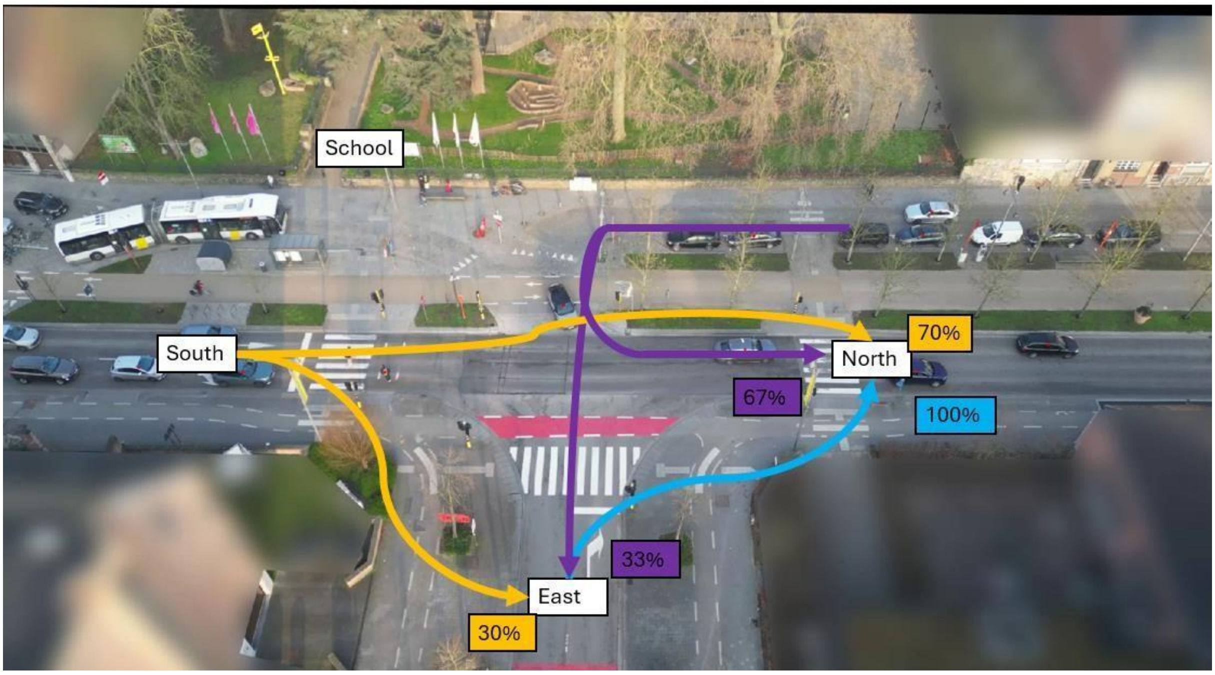


FIGURE 46: O/D Matrix Motorised traffic aerial map Kunstlaan (Own edit, 2024)
Legend: purple line= north, blue line= east, orange line= south, red line= school/west

5.3.3 Occuring speeds

The speeds at which motorised vehicles travel are as follows. The average speed recorded at the intersection of Kunstlaan and Guffenslaan was 28,8km/h. The maximum speed was 42,6km/h. This is lower than the speed limit at the junction, which is 50 km/h. The V85, or what 85% of the drivers drive, is 23,4km/h. This is lower than the permitted speed.

The map below (FIGURE 47: Maximum speeds Kunstlaan (DFS and own edit, 2024)) visuallyizes the maximum speeds, with red indicating speeds closest to 50 km/h and green indicating lower speeds. It is noteworthy that no individual exceeded the maximum speed limit. It is notable that higher speeds (closer to 50 km/h) were observed at the northern end of the Kunstlaan and Guffenslaan intersection. This is a logical occurrence, as drivers are already accelerating for a certain distance and there are no situations that require them to stop again. Consequently, it can be concluded that higher speeds can be reached. It is also noteworthy that higher speeds are observed in the vicinity of the southern traffic lights, which would normally be indicative of lower speeds in anticipation of a potential red light.

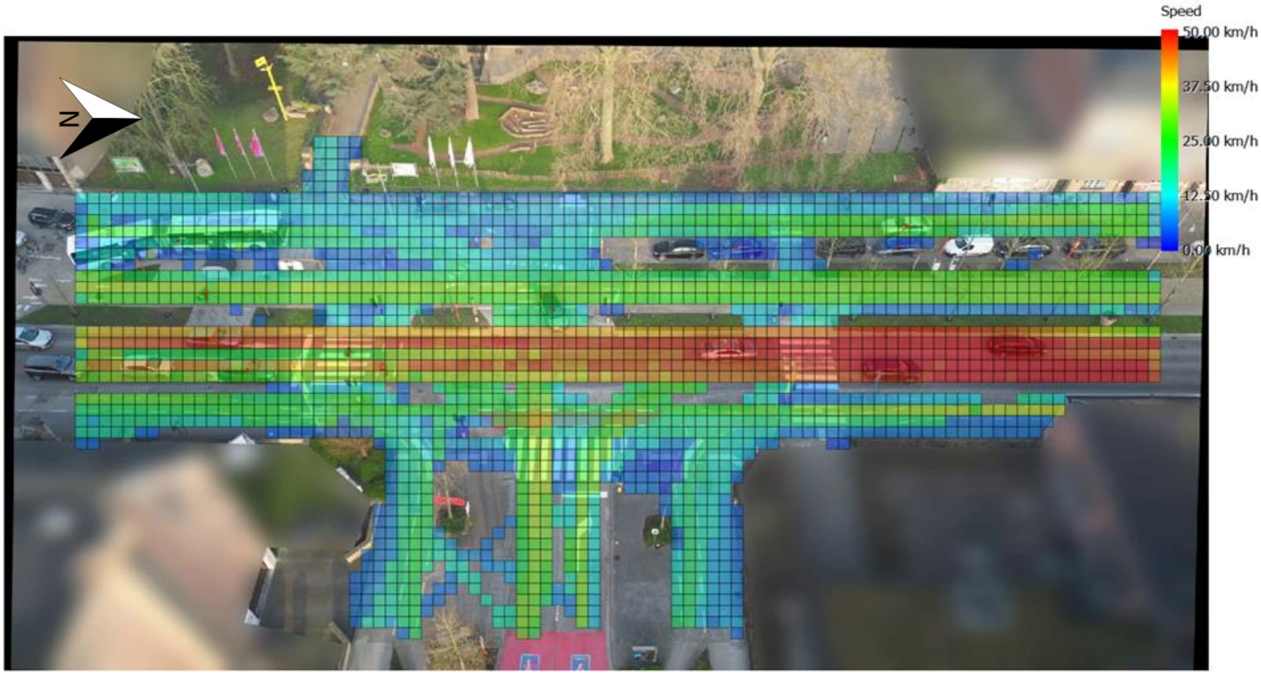


FIGURE 47: Maximum speeds Kunstlaan (DFS and own edit, 2024)

The map below (FIGURE 48: Average speeds Kunstlaan (DFS and own edit, 2024) depicts the average speeds, employing the identical colour scale utilized in the preceding map. The relatively low average speeds of motorised traffic can be attributed to the necessity of stopping at traffic signals. The speeds of motorised traffic are higher than those observed in areas with vulnerable road users, such as pedestrians and cyclists. The average speeds of the cycling-pedestrian path that runs parallel to the north-south route are higher than those of the paths that run parallel to the east and west from it.

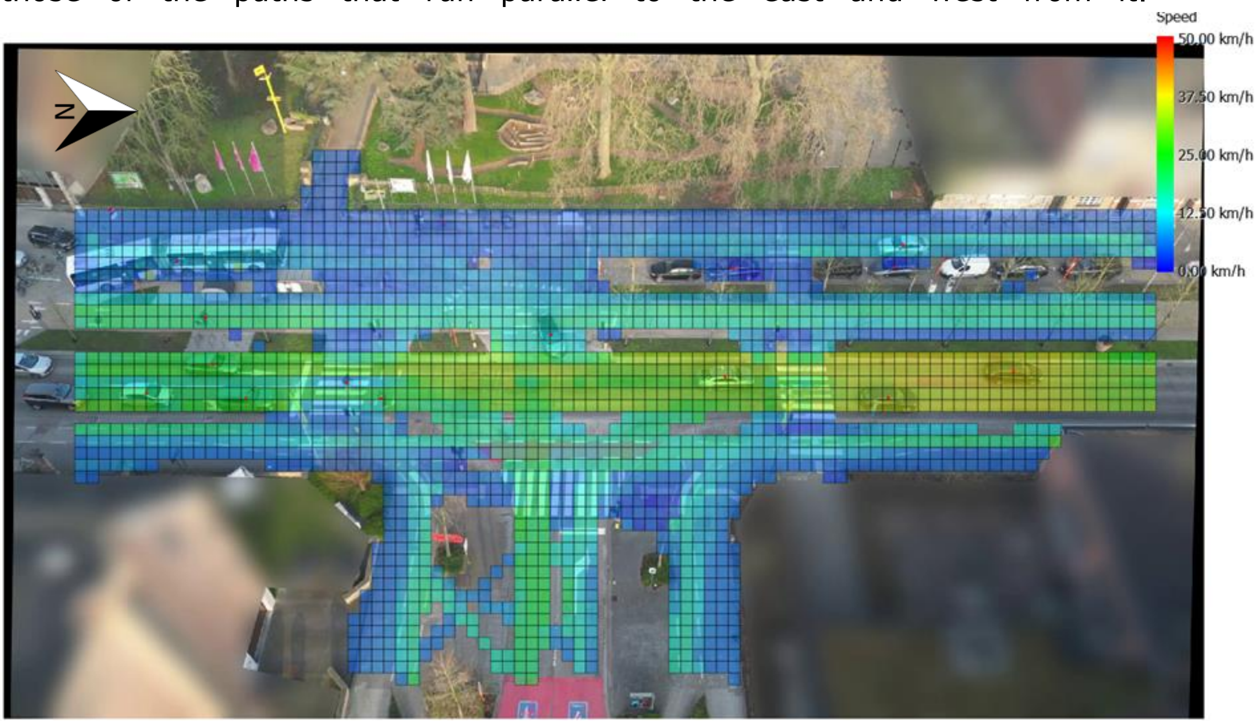


FIGURE 48: Average speeds Kunstlaan (DFS and own edit, 2024)

5.3.4 Trajectory of the road users

The map depicts the trajectories of road users at the intersection of Kunstlaan and Guffenslaan over the recorded period. The category of vulnerable road users, represented in blue, includes pedestrians and cyclists. The purple lines represent motorised traffic, which includes cars, buses, motorcycles, medium vehicles, and heavy vehicles. Motorised vehicles are permitted to utilise designated roads only. It can be observed that vulnerable road users are situated on walkways and cycle lanes. Furthermore, the intersection employs a green traffic light cycle system. To gain a more comprehensive understanding of the crossing facilities, it is advisable to conduct a more detailed examination. The principal crossings occur at the pedestrian crossings, in contrast to the other intersections where no blue lines are visible between the crossings. It can be concluded that the option of diagonal crossing at the intersection itself is not utilised. Upon examination of the area outside the intersection, it is notable that the parallel road in the west and the road in the east outside the main road VRUs do not follow the suggested routes, as indicated by the blue lines. In other words, on the green traffic light cycle intersection, diagonal crossing is permitted but not utilised. However, outside this area where diagonal crossing is prohibited and the designated crossing facilities should be used, blue lines are visible and VRUs do not follow the designated path. In the east, a road has been designated for the use of bicycles, with motorised traffic not having priority. This hypothesis suggests that the blue lines are visible in the middle of the road when crossing because the individuals in question believe they are permitted to do so. Although the red paint indicates that vulnerable road users have priority, the blue lines are visible outside this area.

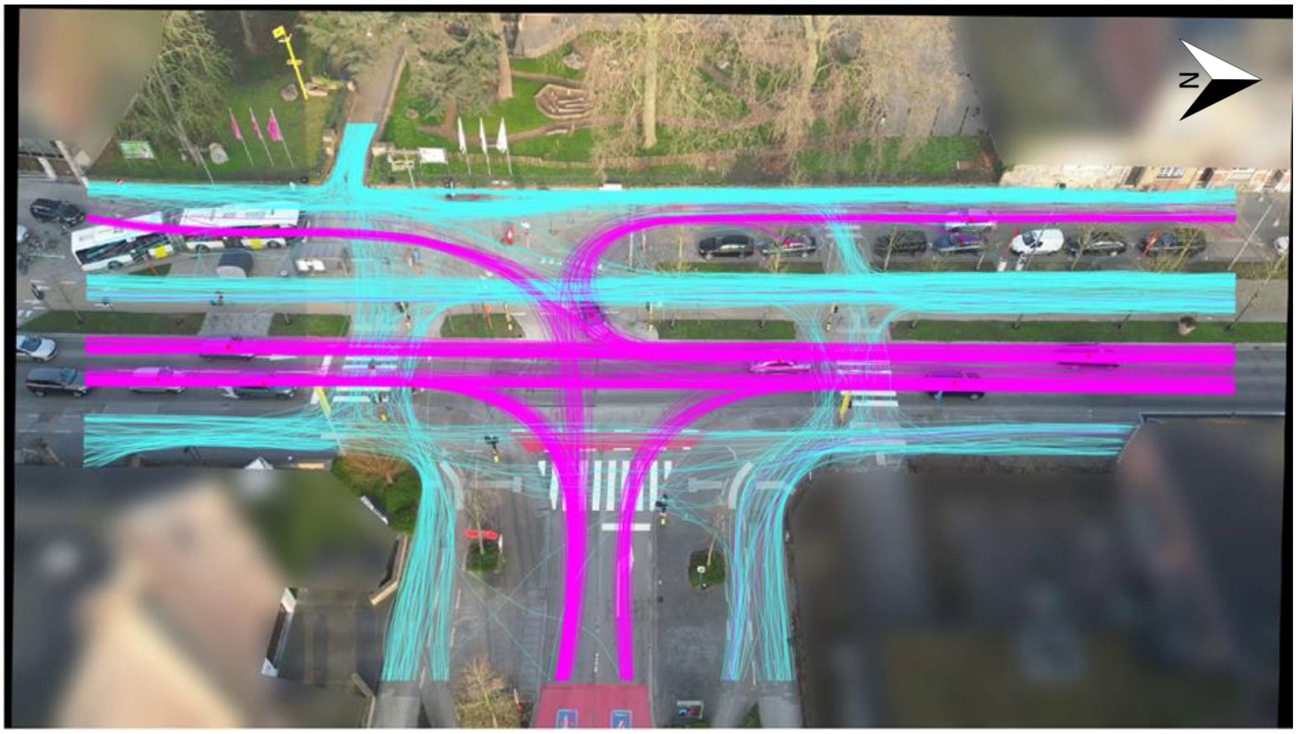


FIGURE 49: Trajectory map Kunstlaan (DFS and own edit, 2024)

The trajectory map (FIGURE 49: Trajectory map Kunstlaan (DFS and own edit, 2024)) and the VRU O/D matrix (FIGURE 46: O/D Matrix Motorised traffic aerial map Kunstlaan (Own edit, 2024)) can be combined, as shown below (FIGURE 50: Trajectory map with O/D Matrix Kunstlaan (DFS and own edit, 2024)). The largest VRU streams travel between south and north. Based on the trajectory lines, it is noticeable that they are travelling on the parallel pedestrian and cycling path that runs north-south and on the pedestrian walkway next to the school (highest concentration of blue lines visible). The conclusion of trajectory lines can be validated by the origin and destination of the VRUs' traffic. The school and the south entrance/exit of the high school attract a great number of VRUs. Lower amounts of VRUs is attracted to the east (low percentages) and this can be validated by the visible less amount of blue lines in that area. As mentioned before, on the intersection, diagonal crossing is not employed; rather, it is utilised on the road in the east below the intersection and on the north-south parallel road next to the school. One potential reason for this behaviour can be that those area, based on the low percentages of O/D traffic do not have that much traffic and VRUs feel like it is safe enough to cross. The hypothesis of a low traffic amount and possible safe crossing are assumption based on the trajectory lines and O/D matrix and is not confirmed. A more detailed look can be taken at the TTC and PET conflict points if is is safe to cross there.

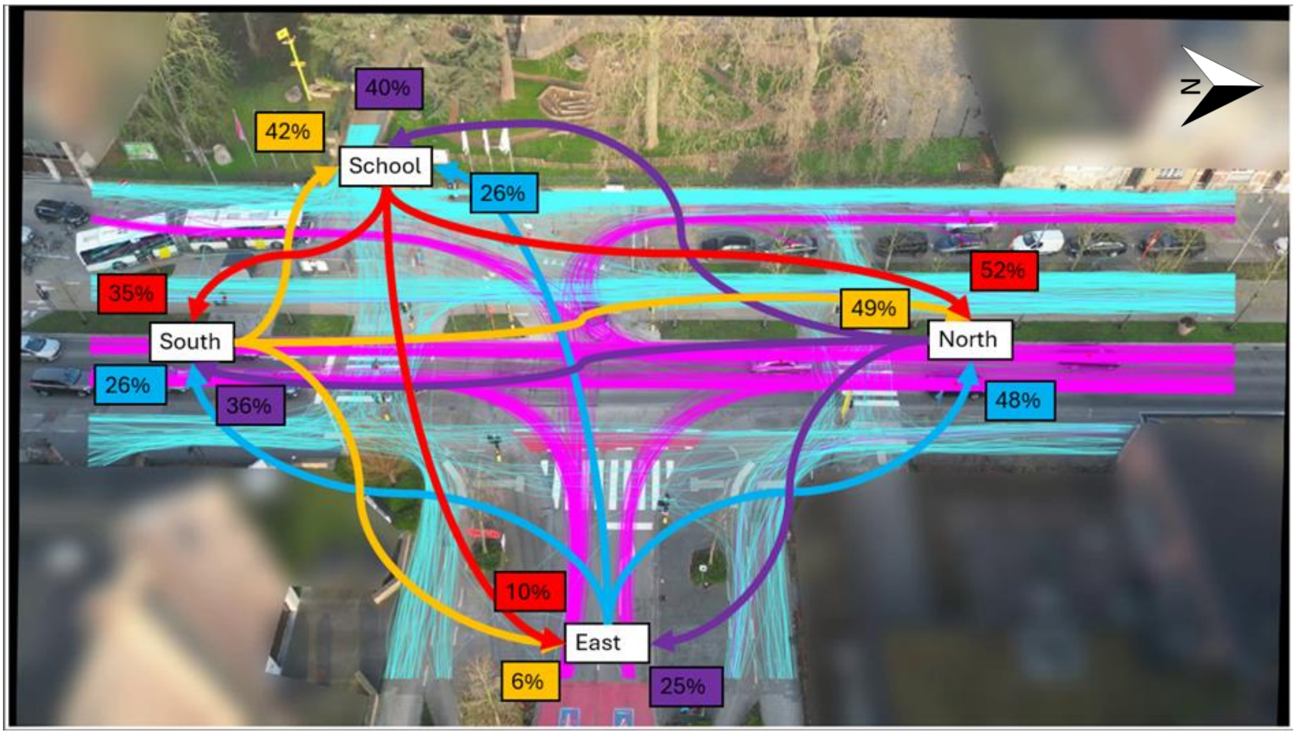


FIGURE 50: Trajectory map with O/D Matrix Kunstlaan (DFS and own edit, 2024)

5.3.5 Proximal indicator TTC

A critical conflict occurred between a bicycle (ID663) and a bus (ID685) at the intersection of Kunstlaan and Guffenslaan, as recorded by TTC data. Although there was no collision, the data registered it as the highest seriousness score. The picture below (FIGURE 51: Critical conflict point TTC Kunstlaan (DFS and own edit, 2024)) shows that the bicycle was not in a dangerous situation and was not standing too close to the road. The registration is considered a mistake.

FIGURE 51: Critical conflict point TTC Kunstlaan (DFS and own edit, 2024)

5.3.6 Conflict points TTC

The previous chapter, Proximal indicator TTC, analysed the highest seriousness score, which is based on the probability of a conflict and the severity, for the TTC parameter, which was recorded as a moderate lane-changing conflict. The map below (FIGURE 52: Conflict grid map TTC Kunstlaan (DFS and own edit, 2024)) shows a grid map based on the TTC indicator. The legend is constructed using threshold values from the literature and is as follows: a time of 0s-1s is a critical TTC score (red), between 1s-1.9s is considered moderate (yellow), and >2s indicates a non- dangerous situation (green to blue). The data indicate that the areas with the red grids are relatively spread around the intersection.

Below, three aerial maps can be found (FIGURE 52: Conflict grid map TTC Kunstlaan (DFS and own edit, 2024) & FIGURE 53: Conflict grid map TTC Kunstlaan motorised traffic (left) and VRUs (right) (DFS and own edit, 2024)). The first image shows conflict points for VRUs and motorised traffic. This does not imply a conflict between VRUs and motorised traffic. Consequently, further aerial maps must be produced in order to gain a more detailed understanding of this matter. The remaining two aerial maps illustrate the occurrence of motorised-motorised conflicts and VRU-VRU conflicts, respectively. A more detailed analysis can be conducted by differentiating between the various types of road users. A greater concentration of red squares is identified around the traffic lights in the south for motorised traffic and further downstream the road in the north. It can be hypothesised that the higher concentration of red squares at these areas is linked to the amount of misfitted bounding boxes. The video footage revealed that the bounding boxes attached to larger vehicles were not fitted correctly, which suggests that they may indicate potential conflicts. With regard to the potential conflict points for VRUs, these are observable on the north-south pedestrian and cycling path parallel to the road. It should be noted that this piece of pavement is not included in the area of the green traffic light cycle, although it is worthy of mention.

FIGURE 52: Conflict grid map TTC Kunstlaan (DFS and own edit, 2024)

FIGURE 53: Conflict grid map TTC Kunstlaan motorised traffic (left) and VRUs (right) (DFS and own edit, 2024)

5.3.7 Kunstlaan TTC graph analysed

This chapter will only discuss a few relevant graphs and tables. Additional graphs and tables can be found in the enclosure chapter for further information.

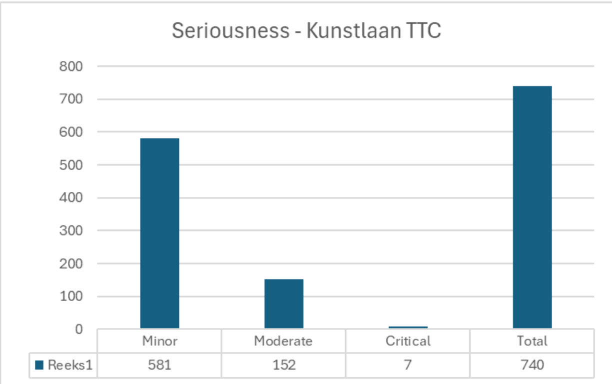


FIGURE 54: Seriousness Kunstlaan TTC (Own edit, 2024)

The above graph, Seriousness Kunstlaan TTC (Own edit, 2024), shows the seriousness of potential accidents at the intersection Kunstlaan and Guffenslaan based on the TTC indicator. Three major categories were identified: minor, moderate and critical. These categories were established based on the probability score and the safety indicator (severity score). Category minor is determined from a Delta V score of above 16, moderate is when the Delta V score is above 64 or has a safety indicator of 2 or above, and everything above those values is categorised as critical. The majority of incidents are minor conflicts (581), with 152 classified as moderate and 7 as critical. Further analysis of minor, moderate and critical conflicts can be found in the graphs below (FIGURE 55: Moderate accidents (left) and critical accidents (right) with type of road user Kunstlaan TTC (Own edit, 2024)). Motorised-motorised accidents account for the majority of moderate accidents (65%), followed by bicycle-motorised conflicts (19%) and pedestrian-motorised accidents (7%). In terms of critical conflicts, 71% or in absolute terms 5 of them involve bicycle-motorised traffic. Critical accidents occur as well between motorised-motorised traffic (29%). The conflicts between vulnerable road users (3% bike-bike, 6% ped- bike) are important for the paper. During a green light cycle, traffic is separated between VRUs and motorised vehicles. Although, 5 critical conflict happened between bicycle-motorised vehicles as is shown as an example on the picture (FIGURE 51: Critical conflict point TTC Kunstlaan (DFS and own edit, 2024**)**) under the chapter proximal indicator TTC. These deserve some more attention.

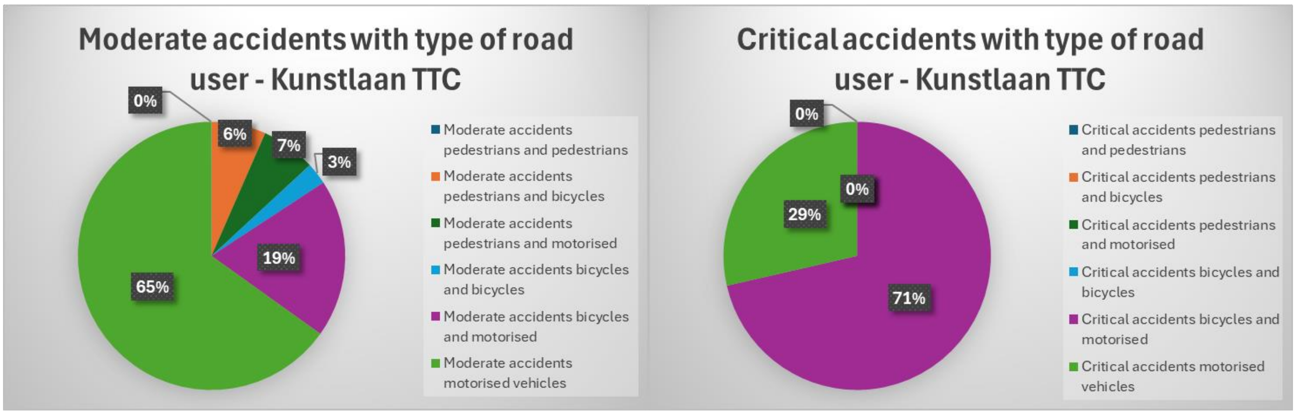


FIGURE 55: Moderate accidents (left) and critical accidents (right) with type of road user Kunstlaan TTC (Own edit, 2024)

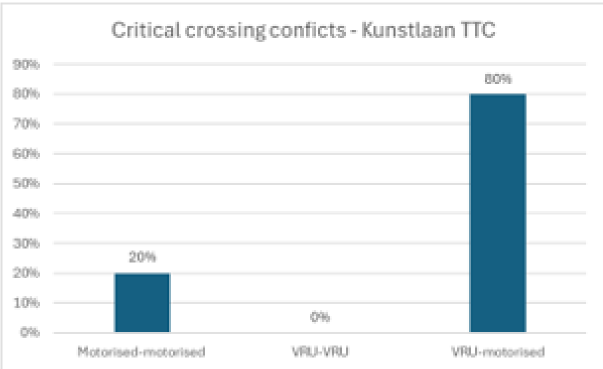
Out of the three types of conflicts observed, 36% were moderate crossing conflicts, 38% were moderate lane-changing conflicts, and 26% were moderate rear-end conflicts. During moderate crossing conflicts, VRU-VRU were represented for 18%, VRU-motorised vehicles 33% and motorised-motorised at 49%. The terminology of the categories is provided by the software, but does not always describe the situation correctly. Therefore, some of the (potential) conflicts are described.

The intersection of Kunstlaan and Guffenslaan exhibited a relatively high incidence of critical conflicts. A more detailed examination of the matter is required. A total of five out of seven incidents (71%) were categorised as crossing conflicts, lane-changing and rear-end collisions, with each accounting for 14% of the total. The highest and most concerning critical crossing conflicts are between VRU and motorised vehicles, with 80% (or four in total) of these conflicts being identified as such. Three of the conflicts involved bicycles positioned close to the road when a motorised vehicle passed. None of the individuals were in imminent danger. One can be linked to the chapter on

Conflict points TTC and the disruptive trajectory line (**FIGURE *49*: Trajectory map Kunstlaan (DFS and own edit, 2024)**) around the cycling road. One critical conflict involved a bicycle crossing the road between cars in a manner that was not permitted.

Looking at the three types of potential moderate conflicts, in all cases motorised-motorised traffic was mostly involved. The highest moderate seriousness score was lane-changing conflict between two cars. The software registered this conflict but in reality it was a misfitted bounding box on a parked car that increased the score. In reality it was not a dangerous situation. The video recordings demonstrate that the bounding boxes around the vehicles, which determine the TTC and PET, are not consistently positioned at the correct location. This may result in higher seriousness values than would be observed in real life, which could contribute to the observed categorisation of seriousness.

It is not uncommon for motorised traffic to be present at an intersection while vulnerable road users (VRUs) are already using the green phase. This phenomenon was not observed at the intersection of Kunstlaan and Guffenslaan. Although on the parallel road adjacent to the north-south road, VRU are observed to cross between the motorised vehicles who are waiting for the traffic light. This phenomenon is not included in the scope of this research, as it does not occur at the intersection where the green traffic light cycle is used and is therefore less relevant. It is, however, important to note that this type of VRU behaviour occurs on the parallel road. The potential conflicts are all located around the traffic lights where motorised traffic is waiting for the light to turn green.



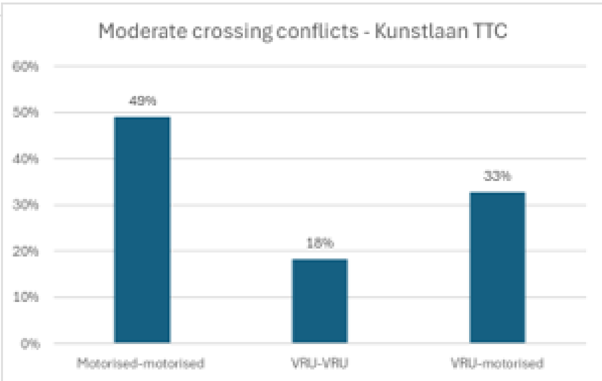


FIGURE 56: Critical (left) and moderate (right) crossing conflicts Kunstlaan TTC (Own edit, 2024)

5.3.8 Proximal indicator PET

The data collected using the PET method at the intersection of Kunstlaan and Guffenslaan indicates that there are some moderate conflicts occurring. These conflicts prompted further investigation, leading to a more detailed examination of the data. The initial six cases exhibiting the highest levels of seriousness were identified as instances of erroneous bounding box delineation. An illustrative example of a bounding box error is provided below (FIGURE 57: example misfitted bounding box (DFS, 2024)). In all instances, a larger vehicle was involved, and the bounding box was misaligned with the vehicle. A subsequent error in the data indicated that the vehicles were in closer proximity to each other than they actually were in real life. The seventh case, which exhibited a high seriousness score and did not involve a misfitted bounding box, involved a pedestrian (ID455) who commenced crossing the road shortly after a car (ID 445) had passed.

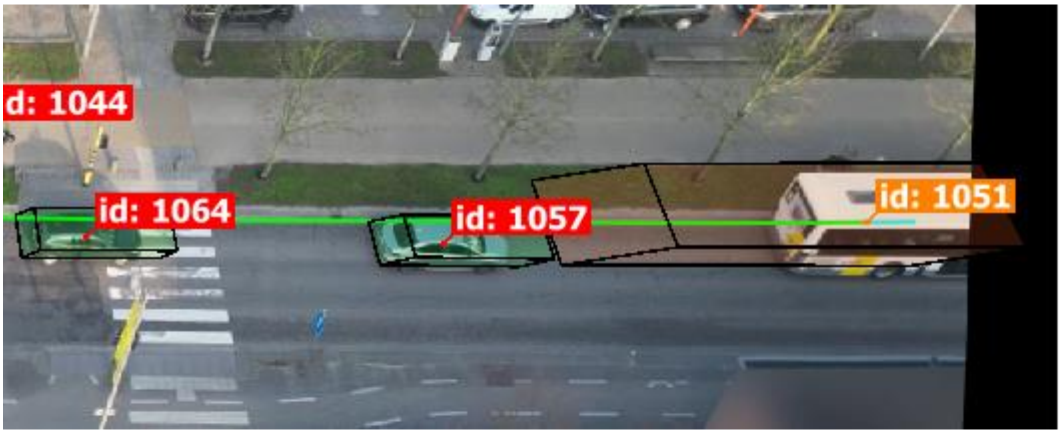


FIGURE 57: example misfitted bounding box (DFS, 2024)

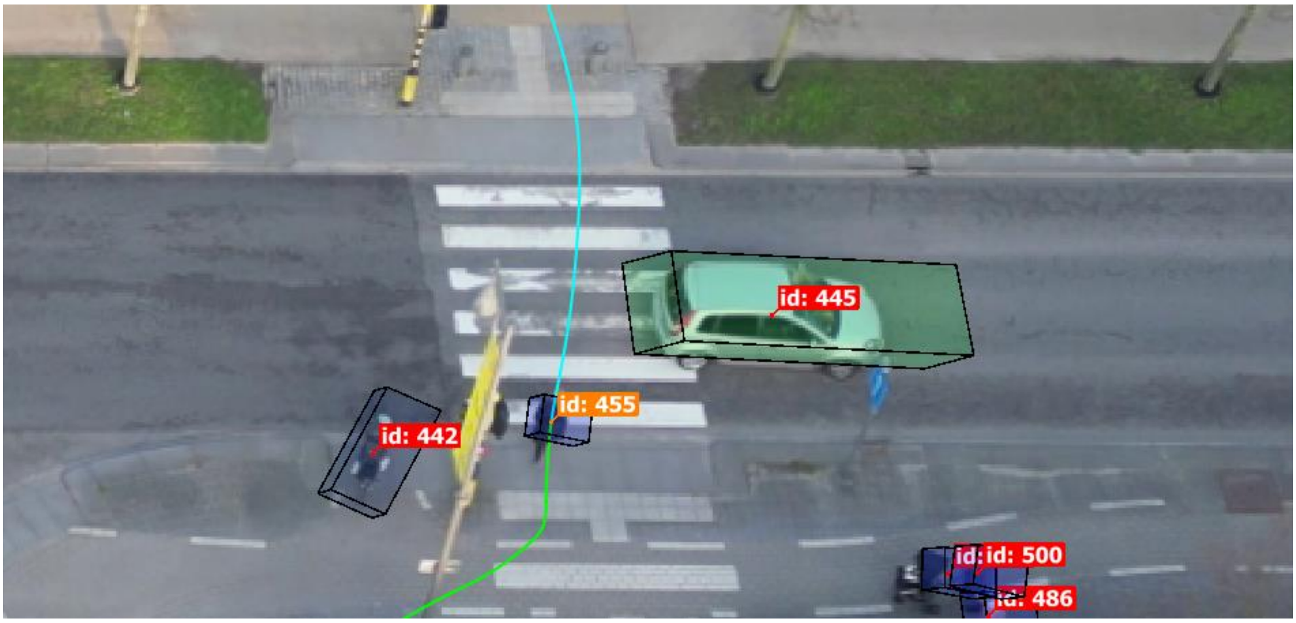


FIGURE 58: Moderate conflict point PET Kunstlaan (DFS, 2024)

5.3.9 Conflict points PET

The threshold value for PET is also situated between 2s and 0s, with 0s signifying a conflict and values above 2s indicating safety. In contrast to TTC, PET does not possess a separation threshold. This is the reason why there are more orange grids on the map in comparison to TTC (**FIGURE *52*: Conflict grid map TTC Kunstlaan (DFS and own edit, 2024)**). The red grids on the parallel road (north-south) in the first image (**FIGURE *59*: Conflict grid map PET Kunstlaan (DFS and own edit, 2024)**) indicate the potential conflicts between the waiting motorised vehicles and VRUs who are crossing in between. This matter was previously discussed in the Kunstlaan TTC graph and can be corroborated with the PET indicator. In general, there are few red grids located at the intersection where a green traffic light cycle is implemented. Instead, they are concentrated on the parallel road and the parallel pedestrian and cycling lane. A similar conclusion can be reached when the types of road users are considered separately.

FIGURE 59: Conflict grid map PET Kunstlaan (DFS and own edit, 2024)

The above aerial map with conflicts (Conflict grid map PET Kunstlaan (DFS and own edit, 2024)) can be analysed in further detail. The following aerial maps (FIGURE 60: Conflict grid map PET Kunstlaan motorised traffic (left), VRUs (right) (DFS and own edit, 2024) illustrate the conflict points for the PET indicator in relation to motorised-motorised interactions (left) and VRU-VRU interactions (right).

A more detailed analysis can be conducted by differentiating between the various types of road users. A greater concentration of red squares is identified in the vicinity of the pedestrian and cycling lane that runs parallel to the north-south road (motorised aerial map). Video footage indicates that motorised traffic travelling in parallel on the south and north roads frequently approaches each other closely when making a turning movement. With regard to the potential conflict points for vulnerable road users (VRU aerial map), these are observable on the north-south pedestrian and cycling path parallel to the road and at the waiting areas at the pedestrian crossings.

FIGURE 60: Conflict grid map PET Kunstlaan motorised traffic (left), VRUs (right) (DFS and own edit, 2024)

5.3.10 Kunstlaan PET graphs analysed

This chapter will only discuss a few relevant graphs and tables. Additional graphs and tables can be found in the enclosure chapter for further information.

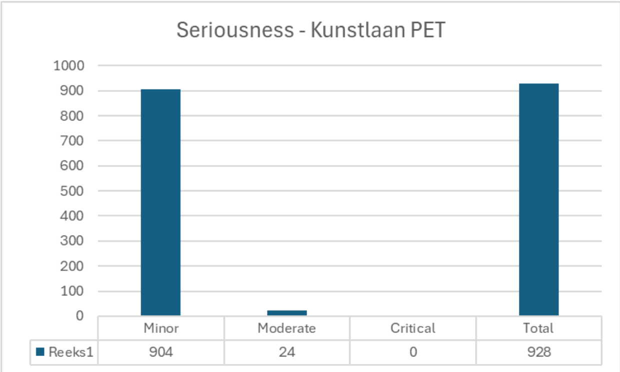


FIGURE 61: Seriousness Kunstlaan PET (Own edit, 2024)

The above graph, Seriousness Kunstlaan PET (Own edit, 2024), shows the seriousness of potential accidents at the intersection Kunstlaan and Guffenslaan based on the PET indicator. The majority of incidents are minor conflicts (904), with 24 classified as moderate and none as critical. Further analysis of minor and moderate conflicts can be found in the graphs below (FIGURE 62: Minor (left) and moderate accidents (right) with type of road user Kunstlaan PET (Own edit, 2024)). Pedestrian-pedestrian accidents account for the majority of minor accidents (58%), followed by motorised- motorised conflicts (29%) and pedestrian-bicycle accidents (7%). In terms of moderate conflicts, 29% of them involve motorised-motorised traffic. Moderate accidents occur as well between pedestrians-motorised, pedestrian-bicycle and bicycle-motorised traffic all 21%. It is noteworthy that the proportion of moderate accidents involving VRU (pedestrians and bicycles) and motorised traffic is higher than that observed at other intersections discussed in this paper based on the PET indicator. A possible explanation could be the misfitted bounding boxes discussed in the chapter Proximal indicator PET.

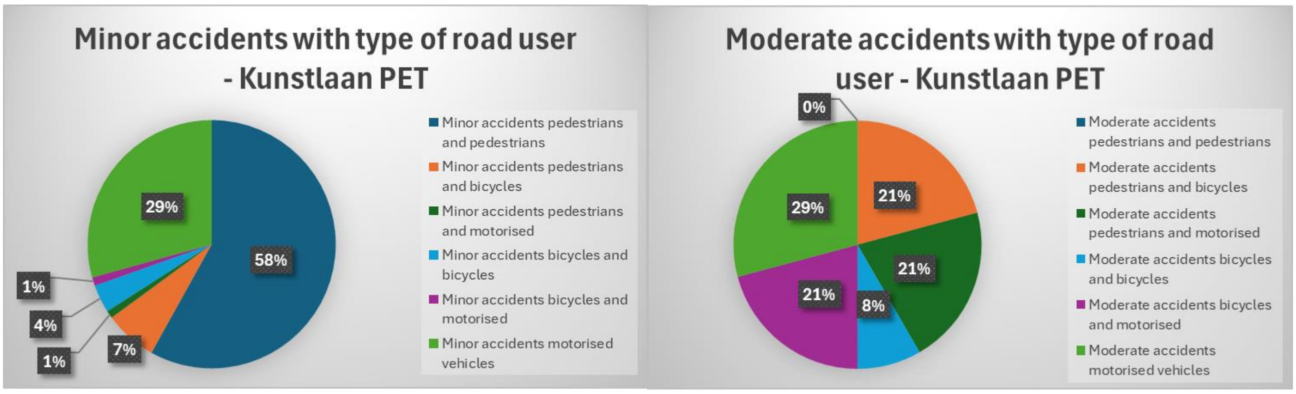


FIGURE 62: Minor (left) and moderate accidents (right) with type of road user Kunstlaan PET (Own edit, 2024)

Examining the types of moderate conflicts, 63% involve crossing while 29%

were categorised as rear-end and 8% involve lane-changing conflicts. Of those involved in crossing conflicts, 53% are motorised-motorised conflicts and 40% between VRUs. While the high amount of VRU-motorised conflicts is concerning, it must be repeated that a high amount of misfitted bounding boxes are the potential reason for this matter. Looking at the VRU-VRU conflicts, based on the footage, these interactions are rather VRU-VRUs moving or passing each other in close proximity.

	#	Total	
Crossing conflicts	15	24	63%
Lane-changing conflict	2	24	8%
Rear-end conflict	7	24	29%

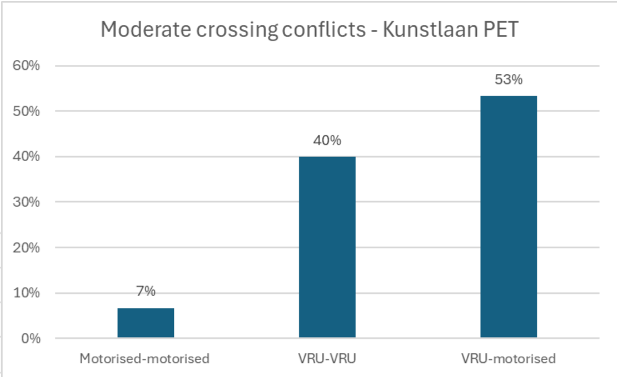


FIGURE 63: Moderate crossing conclicts Kunstlaan PET (Own edit, 2024)

5.4. Summary of results

Proximal factors

In order to conduct a drone-based evaluation of the three locations, it was necessary to identify a number of proximal factors, in addition to other parameters, in order to provide a well-structured and scientific answer to the research questions. A number of different categories of indicators were investigated. The first category of indicators, temporal and spatial, included two specific variables: TTC (Time-To-Collision) and PET (Post-Encroachment-Time). The two proximal factors were the principal indicators for evaluating the locations with drone software. The second category of indicators is that of deceleration and distance. In this category, the indicators DRAC (Deceleration Rate to Avoid the Crash) and PSD (Proportion of Stopping Distance) can be found. As the software utilised in this research did not permit the aforementioned parameters to be employed, they were not included in the subsequent processing of the results. However, they should be considered alongside the other proximal factors, as they possess both advantages and disadvantages, as well as suitability for the task in hand. In order to ascertain the severity of a potential collision, the Delta V indicator was employed. The categories were established on the basis of the probability score and the safety indicator (severity score). The category of "minor" is defined by a Delta V score of above 16. The category of "moderate" is defined by a Delta V score of above 64 or a safety indicator of 2 or above. Finally, the category of "critical" is defined by a Delta V score of above those values. In conclusion, other essential factors were also considered during the data processing, although they were not used as proximal factors. These include data relating to the origin and destination of the traffic on the research locations, modal shift data, and trajectory data.

Conflicts at Kolonel Dusartplein and N702 Koning Boudewijnlaan

At the intersection of R70 Kolonel Dusartplein and N702 Koning Boudewijnlaan in Hasselt, several conflicts arise where a green traffic light cycle is implemented. The highest concentration of red grid conflicts is observed in the vicinity of the pedestrian crossings at the mid-island and the eastern pedestrian crossing. This phenomenon can be attributed to the gathering and waiting of large groups of pedestrians for green lights in these areas, as evidenced by the origin/destination matrix and trajectory map, particularly in the vicinity of the bus stop at the mid-island.

The red grids indicate scenarios where motorised traffic is stationary due to congestion, while VRUs move through the stationary vehicles during their green phase. With regard to the TTC indicator, it can be observed that pedestrian-bicycle accidents account for 46% of minor accidents, while 30% of moderate conflicts involve motorised-motorised traffic. Of the moderate time-to-collision conflicts, 57% were crossing conflicts, 43% were lane-changing conflicts, and no rear-end conflicts were observed.

With regard to the PET indicator, pedestrian-pedestrian accidents account for 41% of minor accidents. The moderate conflicts, which account for 50% of incidents involving pedestrians and bicycles, align with the conflict point map. Of the PET conflicts, 79% were crossing conflicts and 21% were lane-changing conflicts. In 82% of the crossing conflicts, VRUs were involved, while in 67% of the lane-changing conflicts, VRUs were involved. No instances of dangerous conflicts due to excessive speed were observed at Dusart Square.

Seriousness of conflicts at Kolonel Dusartplein and N702 Koning Boudewijnlaan

In order to ascertain the gravity of the conflicts occurring at the intersection of R70 Kolonel Dusartplein and N702 Koning Boudewijnlaan, it is necessary to consider both the severity and probability of these incidents. The severity of conflicts is categorised according to the Delta V threshold values. The designation of a conflict as "minor" is contingent upon a Delta V score exceeding 16. "Moderate" conflicts are characterised by a Delta V score above 64 or a safety indicator of 2 or higher. "Critical" conflicts exceed these values. With regard to the TTC indicator, there were 64 instances of minor conflict, 30 of moderate conflict, and 2 of critical conflict. With regard to the PET indicator, there were 472 instances of minor conflict, 14 instances of moderate conflict, and no instances of critical conflict.

The red grids in the TTC indicator represent areas with TTC values between 1.6 and 0 seconds, which indicate a critical to moderate conflict level. Conversely, the green grids around 2 seconds indicate that no dangerous situation exists. In the case of the PET indicator, red grids indicate values between 2 and 0 seconds, which signify a range of potential conflict severities. Although diagonal crossings are not frequently utilised at this intersection, the relatively high rate of crossing and lane-changing conflicts between vulnerable road users (VRU-VRU) suggests that an increase in diagonal crossings could raise these percentages. It is crucial to acknowledge that these conflicts frequently arise in waiting areas or when pedestrians cross the road before motorised traffic has cleared, rather than directly due to diagonal crossings at the intersection itself.

Conflicts at N80 Sint-Truidersteenweg and N20 Luikersteenweg

At the intersection of R70 Leopoldplein, N20 Luikersteenweg, and N80 Sint-Truidersteenweg, a number of different types of conflict arise. Although the speed limit is often exceeded on Sint-Truidersteenweg, this has not been directly linked to dangerous situations, as the areas of higher speed do not coincide with registered conflict points.

The red grids on the crossing map indicate conflict points primarily at pedestrian waiting areas on the west side and two locations on the east side, with the highest concentration at the latter. This can be correlated with the origin/destination matrix and trajectory map, which demonstrate a high degree of interaction around these crossing facilities. This pattern is consistently observed in both the PET and TTC aerial maps.

On the east 1 and east 2 side of the VRU-VRU aerial map, conflict points are evident

at pedestrian waiting and crossing areas. The high traffic intensity and disruptive movements at this location contribute to the conflicts observed in the trajectory map.
With regard to the TTC indicator, it can be observed that minor accidents are predominantly the result of bicycle-bicycle collisions (47%). Moderate conflicts, which account for 52% of bicycle-bicycle traffic, are comprised of 50% lane-changing conflicts and 43% crossing conflicts. Among moderate crossing conflicts, 54% involve VRUs in motorised traffic, while 46% are VRU-VRU conflicts. One particular observation was that a bus was in motion while a pedestrian was waiting at a crossing, neither party being in immediate danger.
On the eastbound arm, the accumulation of motorised traffic results in pedestrians commencing crossing the road while downstream congestion prevents the clearance of the pedestrian crossing. This issue is specific to this pedestrian crossing and does not affect others.
With regard to the PET indicator, the majority of minor accidents are attributable to motorised-motorised collisions (43%). The proportion of moderate conflicts involving pedestrian-bicycle interactions is 35%. Of these moderate conflicts, 70% are crossing-related, while 30% involve lane-changing. In crossing conflicts, 88% of incidents involve VRUs, while in lane-changing conflicts, this percentage drops to 14%.

Seriousness of conflicts at N80 Sint-Truidersteenweg and N20 Luikersteenweg

The same categorisation for the severity of conflicts is used as before and according to the Delta V threshold values. In order to ascertain the gravity of the conflicts that occur at the intersection of R70 Leopoldplein, N20 Luikersteenweg, and N80 Sint-Truidersteenweg, it is necessary to evaluate both the severity and probability of these incidents. The TTC indicator indicates that there were 713 instances of minor conflict, 168 instances of moderate conflict, and 3 instances of critical conflict. The PET indicator indicates that the majority of incidents (905) were classified as minor conflicts, with 23 incidents classified as moderate conflicts and none classified as critical.
Although diagonal crossings are not a common occurrence at this intersection, there is a relatively high number of conflicts between VRUs. Conversely, the number of conflicts between VRUs related to lane-changing is relatively low. This indicates that an increase in diagonal crossings at this intersection does not necessarily result in a proportional increase in conflict percentages.
The interpretation of red grids in the TTC indicator indicates areas with TTC values between 1.6 and 0 seconds, which may be considered to represent critical to moderate conflict levels. Conversely, green grids around 2 seconds indicate no dangerous situation. In summary, the majority of the grids are green, indicating a generally low level of immediate danger. In contrast to the TTC indicator, the PET indicator does not exhibit a distinct separation. Instead, values are primarily concentrated within the range of 2 to 0 seconds.

Conflicts at R70 Guffenslaan and Kunstlaan

At the intersection of R70 Guffenslaan and Kunstlaan, a variety of conflict types can be observed. No instances of speeding-related conflict were observed at this intersection. The maximum speed observed at the intersection of Kunstlaan and Guffenslaan was not exceeded, and therefore no direct links can be established between speed and conflicts on this intersection. Some potential conflicts for vulnerable road users (VRUs) were observed on the north-south pedestrian and cycling path parallel to the road. It is important to note that this section of pavement is not included in the area of the green traffic light cycle, although it is worthy of mention. The majority of moderate accidents between motorised vehicles were registered by the TTC indicator (65%). With regard to critical conflicts, 71% or with a total of five out of seven incidents involving bicycle-motorised traffic. Further analysis of the footage revealed that the bicycle was not in a dangerous position and was not positioned too close to the road. The registration is considered to be an error. Further details can be provided regarding the type of moderate conflicts for the TTC indicator. These were found to be as follows: 36% were moderate crossing conflicts, 38% were moderate lane-changing conflicts, and 26% were moderate rear-end conflicts. In the case of moderate crossing conflicts, the data revealed that 18% of incidents involved VRU-VRU interactions, 33% involved VRU-motorised vehicles, and 49% involved motorised-motorised interactions. A total of five out of seven incidents (71%) were categorised as crossing conflicts, lane-changing and rear-end collisions, with each accounting for 14% of the total. The most critical crossing conflicts were between vulnerable road users (VRUs) and motorised vehicles, with 80% (or four in total) of the total number of incidents. Three of the conflicts involved bicycles positioned in close proximity to the road when a motorised vehicle passed. None of the individuals were in imminent danger. On the parallel road adjacent to the north-south road, it is observed that VRU cross between the motorised vehicles who are waiting for the traffic light. This phenomenon is not included in the scope of this research, as it does not occur at the intersection where the green traffic light cycle is used and is therefore less relevant.

The PET indicator identified potential conflict points for vulnerable road users (VRU) on the north-south pedestrian and cycling path parallel to the road and at the waiting areas at the pedestrian crossings. A total of 58% of minor accidents were attributed to pedestrian-pedestrian collisions. With regard to moderate conflicts, 29% of these incidents involve motorised vehicles. The majority of moderate conflicts (63%) involved crossing conflicts, while 29% were classified as rear-end collisions and 8% involved lane-changing conflicts. Of those involved in crossing conflicts, 53% are motorised-motorised conflicts and 40% are between vulnerable road users (VRUs).

Seriousness of conflicts at R70 Guffenslaan and Kunstlaan

The same categorisation for the severity of conflicts is employed as previously, with Delta V threshold values serving as the basis for this categorisation. The majority of incidents were classified as minor conflicts (581), with 152 classified as moderate and 7 classified as critical. The PET indicator indicated that the majority of incidents were minor conflicts (904), with 24 classified as moderate and none as critical. The interpretation of red grids in the TTC indicator indicates areas with TTC values between 1.6 and 0 seconds, which may be considered to represent critical to moderate conflict levels. Conversely, the presence of green grids around 2 seconds indicates that no dangerous situation exists. In conclusion, the majority of the grids are green, indicating a generally low level of immediate danger. In contrast to the TTC indicator, the PET indicator does not exhibit a distinct separation. Instead, the values are primarily concentrated within the range of 2 to 0 seconds.

TABLE 13: Summary overview three research locations (Source: Own edit, 2024)

Summary overview					
Location 1 Dusart		Location 2 Sint-Truidersteenweg		Location 3 Kunstlaan	
High concentration of potential conflict point: eastern pedestrian crossing and mid-island (bus stop)		High concentration of potential conflict point: pedestrian waiting areas west, east 1 and east 2		High concentration of potential conflict point: north-south pedestrian-cycling path parallel to the main road	
TTC	PET	TTC	PET	TTC	PET
46% minor conflicts pedestrian-bicycle	41% minor conflicts pedestrian-pedestrian	47% minor conflicts bicycle-bicycle	43% minor conflicts motorised-motorised	65% moderate conflicts motorised-motorised	58% minor conflicts pedestrian-pedestrian
30% moderate conflicts motorised-motorised	50% moderate conflicts pedestrian-bicycles	52% moderate conflicts bicycle-bicycle	35% moderate conflicts pedestrian-bicycle	71% critical conflicts bicycle-motorised	29% moderate conflicts motorised-motorised
57% crossing -, 43% lane-changing conflicts	79% crossing -, 21% lane-changing conflicts	50% lane-changing -, 43% crossing conflicts	70% crossing -, 30% lane-changing conflicts	71% crossing -, 14% lane-changing -, 14% rear-end conflicts	63% crossing -, 29% rear-end -, 8% lane-changing
64 minor, 30 moderate, 2 critical conflict	472 minor, 14 moderate, 0 critical conflict	713 minor , 168 moderate, 3 critical conflict	905 minor , 23 moderate, 0 critical	581 minor, 152 moderate, 7 critical conflict	904 minor, 24 moderate, 0 critical conflict

6. Discussion

6.1. Suggestion to make the infrastructure safer

As illustrated in the summary overview table above (Summary overview three research locations (Source: Own edit, 2024), the various locations exhibit a diverse array of conflict types and road user profiles. These observations are based on proximal indicators. Further research is necessary to determine the most effective countermeasures for improving the infrastructure at the three research locations. Nevertheless, based on the data presented in this paper, some suggestions can be made. At any of the three research locations, the presence of a green traffic light cycle is indicated. This indicates that road users are not aware that a green traffic light cycle is in operation at the intersections. It is evident that the public is unaware of the option of diagonal crossing. This is visibly represented on the trajectory maps, with the majority of conflict points situated at the crossing waiting areas. It is recommended that appropriate signage be installed at the intersection to inform road users that they are on a green traffic light cycle intersection.

On the Dusart square, it is possible that the diagonal crossing on the square will be relocated to the road itself, which may result in an increase in potential conflicts. The Sint-Truidersteenweg and Kunstlaan do not present this issue. At the three locations, VRUs commence crossing the road while motorised traffic is still in the process of clearing the intersection. The data presented in this paper indicates that the size of the intersection is not influencing this variable; rather, it is the intensity of traffic during the congestion period that plays a role. It is recommended that the signal timing be adjusted to ensure that motorised traffic is cleared from the intersection before VRUs commence crossing. In addition to the signage, it is recommended that road users be provided with information regarding the contents of a green traffic light cycle, the advantages and disadvantages thereof, and the circumstances under which different VRUs are crossing each other during diagonal crossing.

6.2. Extrapolating findings to complete green traffic light cycle sites

The principal findings of the so-called "hidden" green traffic light cycles have already been referenced on several occasions. The objective of this discussion chapter is to ascertain whether the results can be extrapolated to encompass a complete green traffic light cycle. As previously stated, the size of intersections where hidden green traffic light cycles were implemented does not influence the number of potential conflict points. The number and location of potential conflict points can be attributed to the intensity of traffic during congestion periods and the fact that conflict points and VRUS cross before the intersection is cleared of motorised traffic. Furthermore, the option of diagonal crossing, which is permitted at a green traffic light cycle site, is not frequently utilised.

This chapter is primarily concerned with the discussion and raising of awareness regarding the topic of extrapolating the findings, rather than with the continuation and proof of statements. The physical dimensions of the intersection do not contribute to the potential for conflict on a complete green traffic light cycle. Rather, they are again related to traffic intensity, traffic behaviour, and signal timing. The level of congestion will remain unchanged from a 'hidden' to a

'complete' site. As a significant factor in the potential for conflict, this variable can be extrapolated to a 'complete' green traffic light cycle. As the extrapolation progresses towards a 'complete' green traffic light cycle, information is provided to road users, which may result in an increase in diagonal crossing. At one location (Dusart Square), it was predicted that an increase in diagonal crossings might lead to an increase in potential conflicts. However, this is not the case for the two other locations (Sint-Truidersteenweg and Kunstlaan).
To corroborate the aforementioned information, a comparison between a 'hidden' and 'complete' green traffic light cycle site must be conducted in a scientific manner.

7. Conclusion main research question

With the information that is collected by this research and with the help of the sub research questions, an answer can be given to the main research question which was the following: "What is the effect of the infrastructural intervention of a green traffic light cycle, with the aim of improving road safety for road users following the STOP principle, based on drone technology and its proximal factors?"

It can be observed that the advantages of a green traffic light cycle are not being utilised at any of the three research locations that have been investigated. It can be hypothesised that neither of the locations (Dusart, Sint-Truidersteenweg and Kunstlaan) indicate the implementation of a green traffic light cycle. This is one of the reasons why the conflict points are located at the waiting areas of the pedestrian crossings rather than at the intersection itself. The proximal indicators at the three research locations indicate different conflicts and different road users involved at the waiting areas. This may be indicative of the potential for these types of conflicts at the waiting areas to extend to the intersection itself, should the advantages of a green traffic light cycle, for instance diagonal crossing, be more utilised. As previously stated in the literature, conflicts between vulnerable road users (VRUs) during the green traffic light cycle have been observed. However, this research paper does not provide evidence to confirm this. Nevertheless, it can be confirmed that the majority of potential conflicts at the waiting areas of the crossings are of a relatively minor nature. A significant finding of the investigation was that intersections, regardless of size, present challenges in the clearance of motorised traffic. The VRUs commence crossing the road between the motorised traffic before the latter has had an opportunity to clear the intersection. Another noteworthy observation pertains to the use of drone technology. During the software analysis, issues were identified that necessitate further investigation. The positioning of bounding boxes was frequently erroneous, resulting in the misclassification of potential conflicts. The severity and probability (seriousness) of the incidents were increased to reflect a more serious scenario than that observed in real life.

8. Limitations and recommendations future research

The principal limitations of this paper lie in the data collection and processing. The limitations of the data will be discussed in a chronological order, with reference to the steps of the research.

It is not possible to maintain the drone in a fixed location during the data collection period, due to the nature of the recording process. This results in vertical and horizontal deformations. An error formula is provided in the calculations to enhance the reliability of the data. It is important to note that this should be included in the research to avoid any potential limitations. However, it is also essential to acknowledge that minor errors may have an impact. During the data collection process, it was challenging to select an optimal angle to mitigate the impact of shadowing errors. It is possible that road users may be misidentified or not identified at all.

During the data processing, the software did not permit the utilisation of all the proximal factors that had been identified in the literature review. Only two of the listed variables, namely, TTC and PET, were included in the data processing. Furthermore, it is important to note that the modal split was established using entry and exit gates. It is possible that some registered road users may be misidentified, which could result in minor discrepancies in the data. Nevertheless, the overall differences between categories will remain consistent.

Upon analysis of the data, it became evident that errors had been made in the delineation of the bounding boxes around road users. These errors included misaligned boxes, which appeared to be either too large or not centered within the vehicle. This was particularly evident in the case of larger vehicles, such as buses and medium and heavy vehicles. As a result, the resulting conflicts were often of a higher severity than they actually were. These errors were subsequently identified and filtered out by manual examination of the extreme conflict values.

The categorisation of conflicts was constrained by the software. Crossing conflicts, lane-changing conflicts and rear-end conflicts were the categories, and they were frequently misaligned in situations. For instance, a lane-changing conflict is more appropriate for motorised vehicles but not for VRUs.

The following recommendations for future research are proposed: As previously stated, the intersections of Dusart, Sint-Truidersteenweg and Kunstlaan, as of June 2024, lack appropriate signage indicating that a green traffic light cycle is in operation at the aforementioned intersections. It would be of interest to ascertain the differences in outcomes (trajectories of road users, change in conflict point locations, difference in the severity of potential conflicts, etc.) when signage is implemented and road users are informed of the green traffic light cycle (e.g., diagonal crossing).

As the matter of bounding boxes was discussed, further research on this topic could prove beneficial for the advancement of drone research. As indicated in the literature, the shape of the surrounding area may also influence the results. The shape of this space is contingent upon the type of road user, speed, and pedestrian volume (Wang et al., 2024). The area around pedestrians is semi-circular, while that around bicyclists is semi-elliptical. The dimensions of the safe space increase with higher speeds, but decrease with increased pedestrian traffic volumes.

6 Implementation timeline

Table 6: Adjusted timeline for semester 2 Source: own edit, 2024

Time period	**Detailed activity**
April – August	➢ Developing the plan of approach ➢ Obtain drone certificate
September - October	➢ In-depth literature review ➢ Develop problem statement ➢ Select the infrastructural intervention
November - December	➢ Learn more about proximal safety factors ➢ Supplement methodology ➢ Prepare the latest steps for drone data collection
January – February	➢ Work on literature and methodology part ➢ Prepare the data collection
March	➢ Week of 4/03–8/03 collecting data on two square green intersections ➢ Week 11/03–15/03 collecting data on the third square green intersection ➢ From 11/03–31/03 process the data in Data from Sky
April	➢ 1/04–5/04 ask for feedback on data reporting ➢ 8/04-16/04 rework feedback on data reporting ➢ 22/04-30/04 write conclusion, recommendations and final parts
May	➢ 6/05-15/05 Finish a final draft version of thesis ➢ 23/05-1/06 rework all the remaining feedback
June	➢ Final version ➢ Oral defence prepared

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8 Appendix

8.3 Data Dusart

Seriousness PET Dusart

% Seriousness	
Minor	472
Moderate	14
Critical	0
Total	486

Minor accidents with type of road user PET - Dusart

Description	#	Total	%
Minor accidents pedestrians and pedestrians	191	472	40%
Minor accidents pedestrians and bicycles	77	472	16%
Minor accidents pedestrians and motorised	10	472	2%
Minor accidents bicycles and bicycles	21	472	4%
Minor accidents bicycles and motorised	3	472	1%
Minor accidents motorised vehicles	170	472	36%

Type of road user and minor crossing conflict type PET - Dusart

	#	Total	
Crossing conflicts	63	472	13%
Motorised-motorised	0	63	0%
VRU-VRU	58	63	92%
VRU-motorised	5	63	8%

Type of road user and minor lane-changing conflict type PET - Dusart

	#	Total	
Lane-changing conflict	64	472	14%
Motorised-motorised	0	64	0%
VRU-VRU	63	64	98%
VRU-motorised	1	64	2%

Type of road user and minor rear-end conflict type PET - Dusart

	#	Total	
Rear-end conflict	346	472	73%
Motorised-motorised	170	346	49%
VRU-VRU	168	346	49%
VRU-motorised	8	346	2%

Moderate accident with type of road user - PET Dusart

Description	#	Total	%
Moderate accidents pedestrians and pedestrians	2	14	14%
Moderate accidents pedestrians and bicycles	7	14	50%
Moderate accidents pedestrians and motorised	3	14	21%
Moderate accidents bicycles and bicycles	2	14	14%
Moderate accidents bicycles and motorised	0	14	0%
Moderate accidents motorised vehicles	0	14	0%

Type of road user and moderate crossing conflict type PET - Dusart

	#	Total	
Crossing conflicts	11	14	79%
Motorised-motorised	0	11	0%
VRU-VRU	9	11	82%
VRU-motorised	2	11	18%

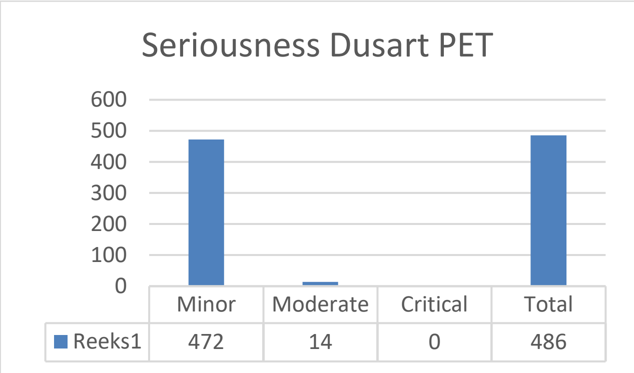
Type of road user and moderate lane-changing conflict type PET - Dusart

	#	Total	
Lane-changing conflict	3	14	21%
Motorised-motorised	0	3	0%
VRU-VRU	2	3	67%
VRU-motorised	1	3	33%

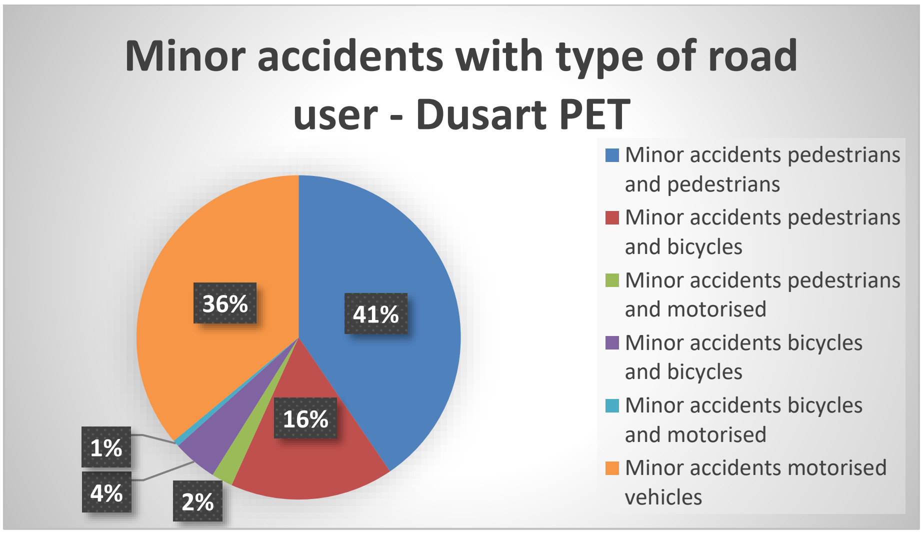
Type of road user and moderate rear-end conflict type PET - Dusart

	#	Total	
Rear-end conflict	0	14	0%
Motorised-motorised	0	0	####
VRU-VRU	0	0	####
VRU-motorised	0	0	####

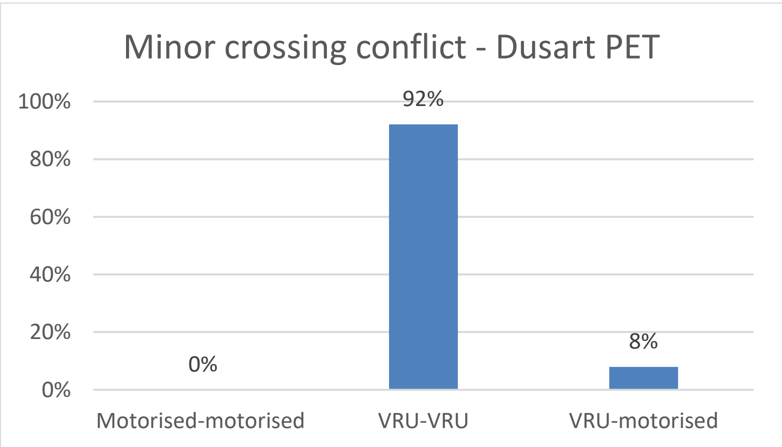
Seriousness Dusart



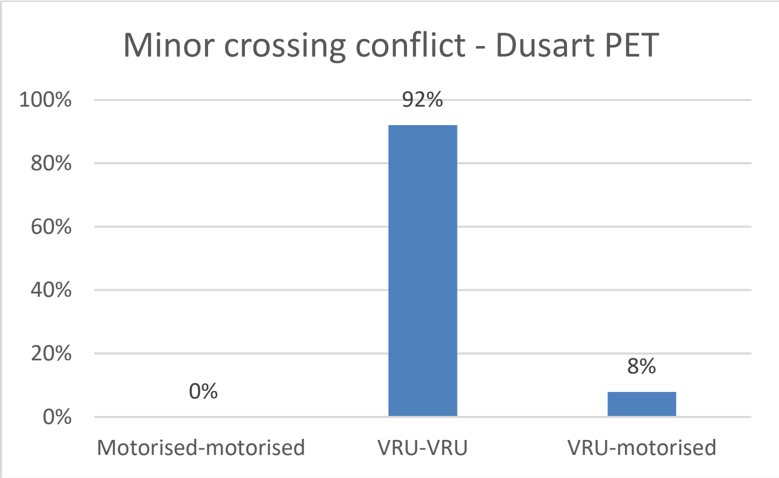
Minor accidents with type of road user PET - Dusart



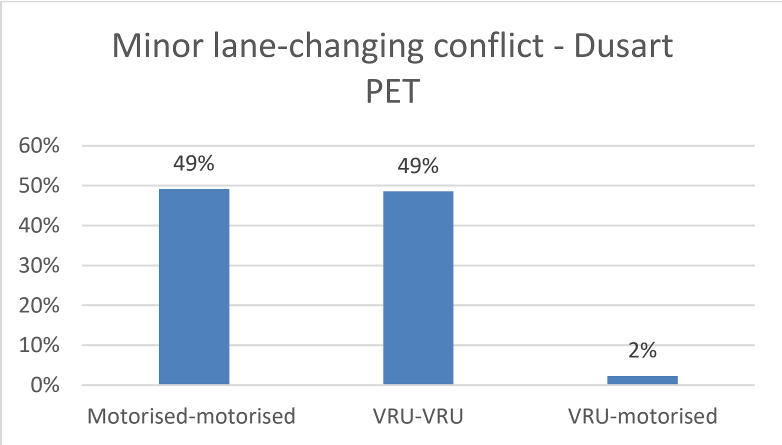
Type of road user and minor crossing conflict type PET - Dusart



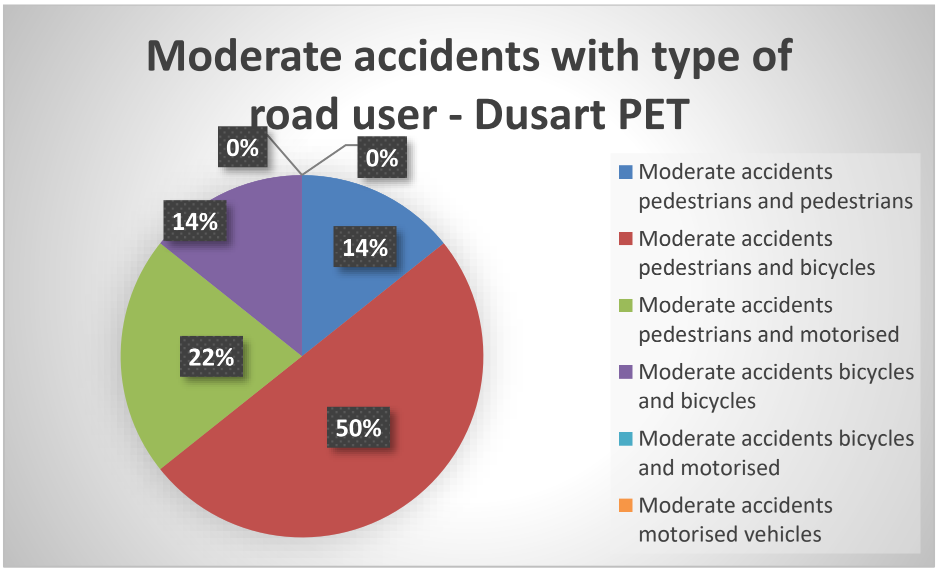
Type of road user and minor lane-changing conflict type PET - Dusart



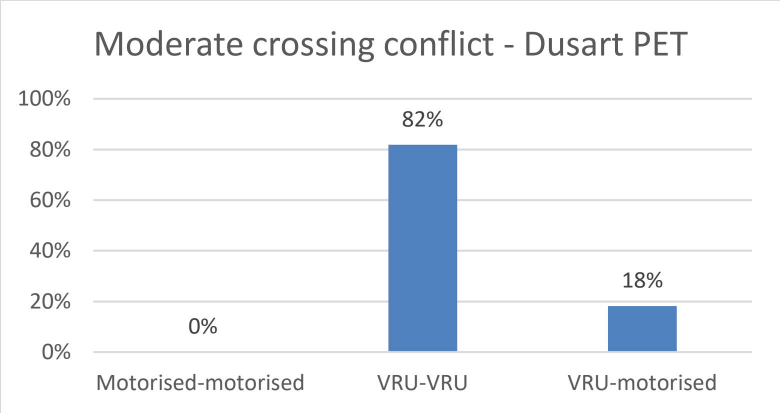
Type of road user and minor rear-end conflict type PET - Dusart



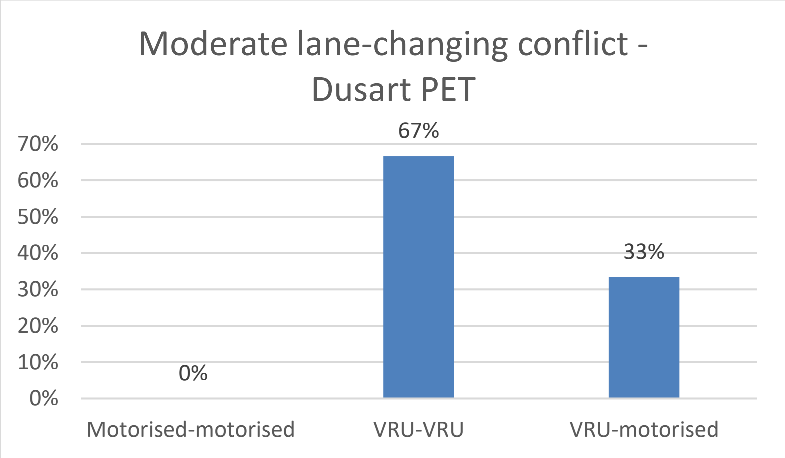
Moderate accident with type of road user PET - Dusart



Type of road user and moderate crossing conflict type PET - Dusart



Type of road user and moderate lane-changing conflict type PET - Dusart



Seriousness TTC Dusart

% Seriousness	
Minor	64
Moderate	30
Critical	2
Total	96

Minor accidents with type of road user TTC – Dusart

Description	#	Total	%
Minor accidents pedestrians and pedestrians	0	64	0%
Minor accidents pedestrians and bicycles	29	64	45%
Minor accidents pedestrians and motorised	4	64	6%
Minor accidents bicycles and bicycles	14	64	22%
Minor accidents bicycles and motorised	3	64	5%
Minor accidents motorised vehicles	14	64	22%

Type of road user and minor crossing conflict type TTC - Dusart

	#	Total	
Crossing conflicts	24	64	38%
Motorised-motorised	4	24	17%
VRU-VRU	16	24	67%
VRU-motorised	4	24	17%

Type of road user and minor lane-changing conflict type TTC - Dusart

	#	Total	
Lane-changing conflict	18	64	28%
Motorised-motorised	10	18	56%
VRU-VRU	6	18	33%
VRU-motorised	2	18	11%

Type of road user and minor rear-end conflict type TTC - Dusart

	#	Total	
Rear-end conflict	22	64	34%
Motorised-motorised	0	22	0%
VRU-VRU	21	22	95%
VRU-motorised	1	22	5%

Moderate accident with type of road user TTC - Dusart

Description	#	Total	%
Moderate accidents pedestrians and pedestrians	0	30	0%
Moderate accidents pedestrians and bicycles	4	30	13%
Moderate accidents pedestrians and motorised	8	30	27%
Moderate accidents bicycles and bicycles	7	30	23%
Moderate accidents bicycles and motorised	2	30	7%
Moderate accidents motorised vehicles	9	30	30%

Type of road user and moderate crossing conflict type TTC - Dusart

	#	Total	
Crossing conflicts	17	30	57%
Motorised-motorised	5	17	29%
VRU-VRU	6	17	35%
VRU-motorised	6	17	35%

Type of road user and moderate lane-changing conflict type TTC - Dusart

	#	Total	
Lane-changing conflict	13	30	43%
Motorised-motorised	4	13	31%
VRU-VRU	5	13	38%
VRU-motorised	4	13	31%

Type of road user and moderate rear-end conflict type TTC - Dusart

	#	Total	
Rear-end conflict	0	30	0%
Motorised-motorised	0	0	####
VRU-VRU	0	0	####
VRU-motorised	0	0	####

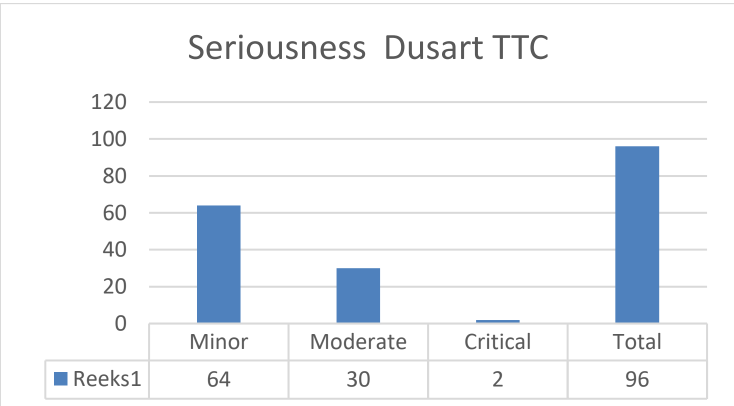
Critical accident with type of road user TTC - Dusart

Description	#	Total	%
Critical accidents pedestrians and pedestrians	0	2	0%
Critical accidents pedestrians and bicycles	0	2	0%
Critical accidents pedestrians and motorised	0	2	0%
Critical accidents bicycles and bicycles	0	2	0%
Critical accidents bicycles and motorised	0	2	0%
Critical accidents motorised vehicles	2	2	100%

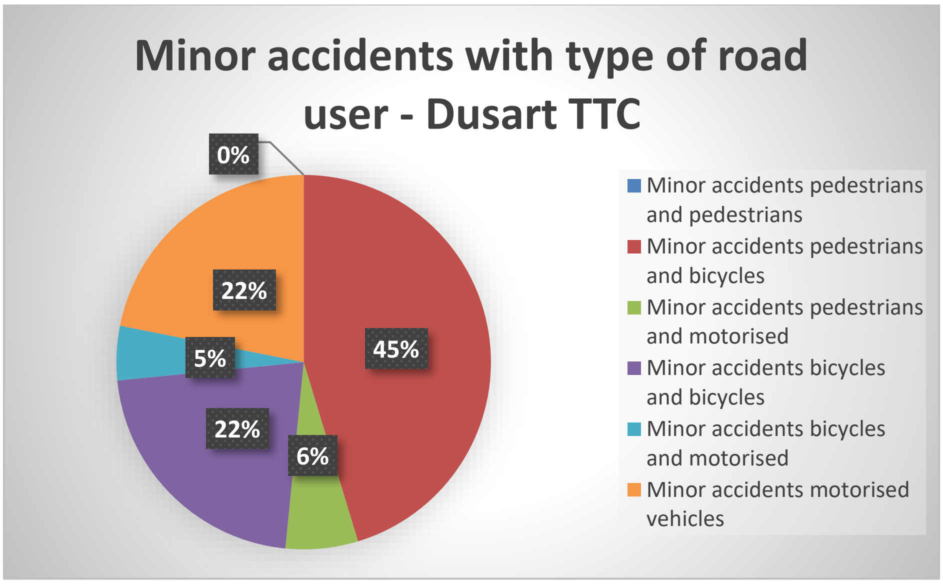
Type of road user and type of critical crossing conflict type TTC - Dusart

	#	Total	
Crossing conflicts	2	2	100%
Motorised-motorised	2	2	100%
VRU-VRU	0	0	########
VRU-motorised	0	0	########

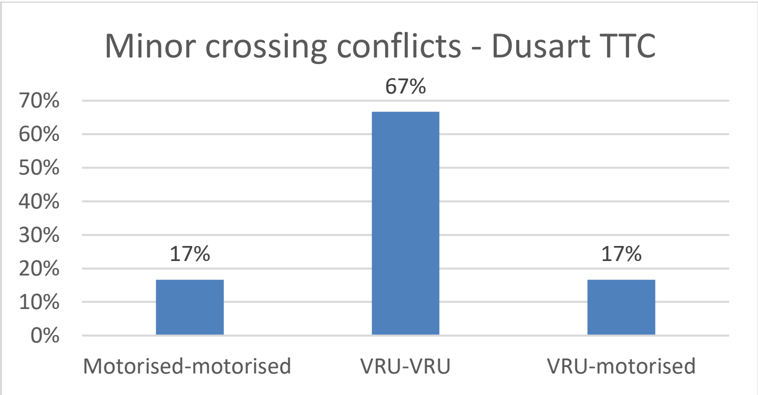
Seriousness TTC Dusart



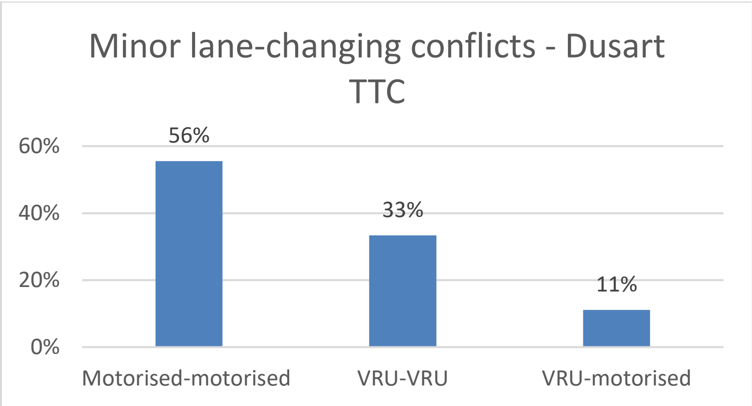
Minor accidents with type of road user TTC - Dusart



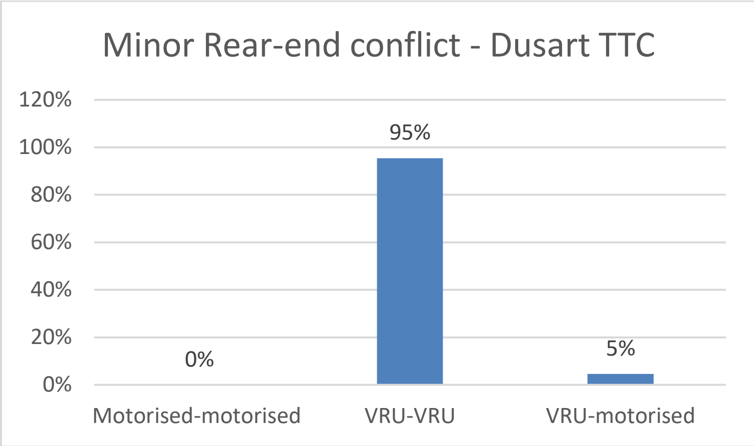
Type of road user and minor crossing conflict type TTC - Dusart



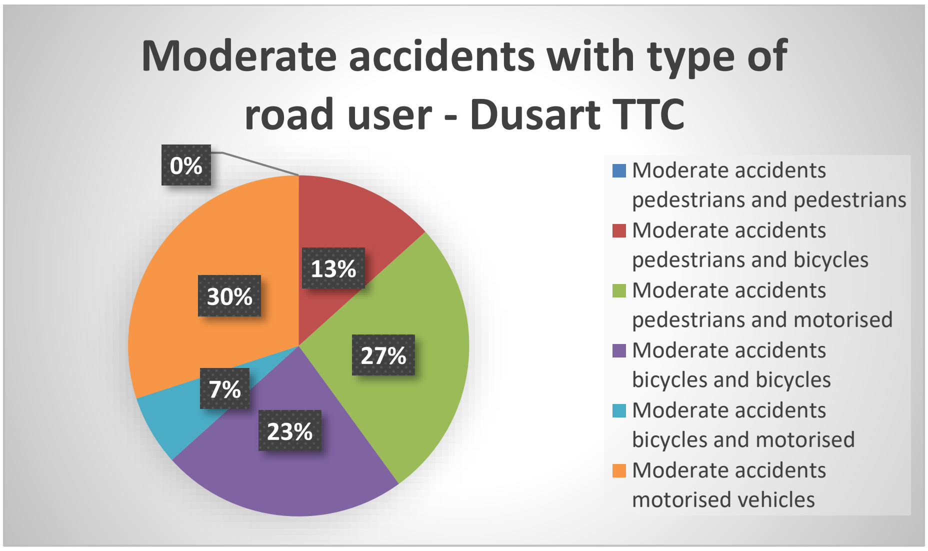
Type of road user and minor lane-changing conflict type TTC - Dusart



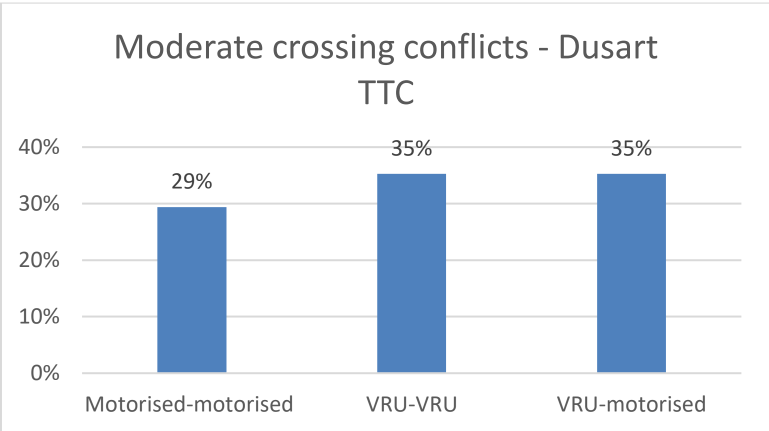
Type of road user and minor rear-end conflict type TTC - Dusart



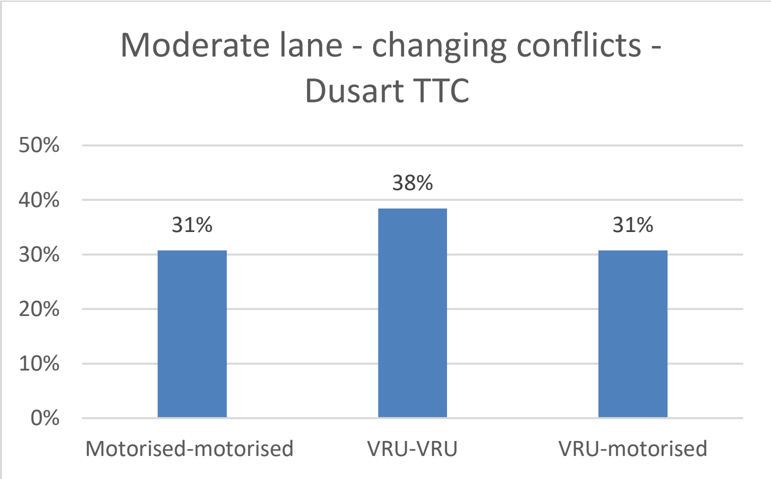
Moderate accident with type of road user TTC - Dusart



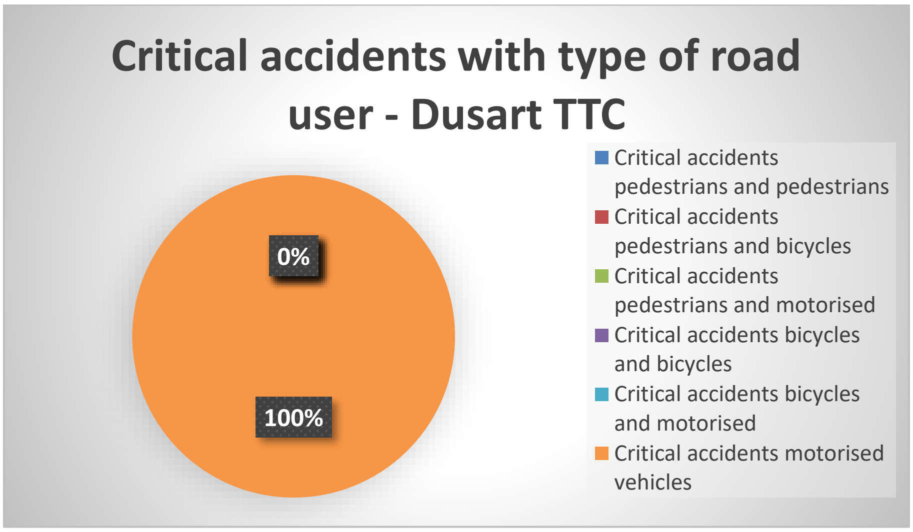
Type of road user and moderate crossing conflict type TTC - Dusart



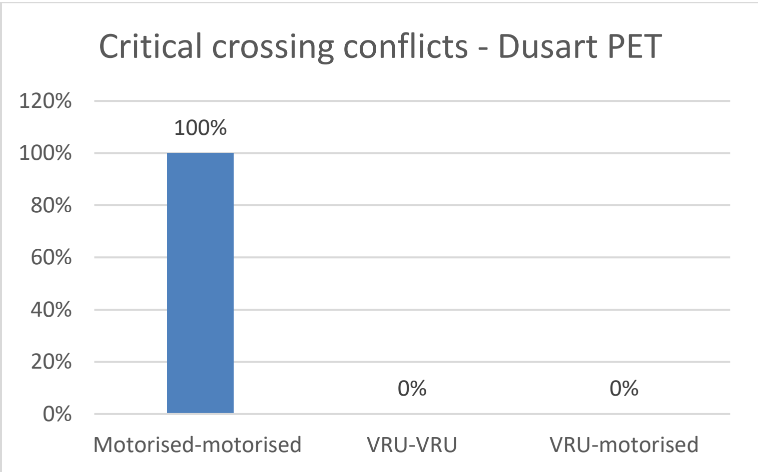
Type of road user and moderate lane-changing conflict type TTC - Dusart



Critical accident with type of road user TTC - Dusart



Type of road user and type of critical crossing conflict type TTC - Dusart



8.4 Data Kunstlaan and Guffenslaan

Seriousness PET Kunstlaan

% Seriousness	
Minor	904
Moderate	24
Critical	0
Total	928

Minor accidents with type of road user PET - Kunstlaan

Description	#	Total	%
Minor accidents pedestrians and pedestrians	525	904	58%
Minor accidents pedestrians and bicycles	62	904	7%
Minor accidents pedestrians and motorised	9	904	1%
Minor accidents bicycles and bicycles	33	904	4%
Minor accidents bicycles and motorised	10	904	1%
Minor accidents motorised vehicles	265	904	29%

Type of road user and minor crossing conflict type PET - Kunstlaan

	#	Total	
Crossing conflicts	137	904	15%
Motorised-motorised	12	137	9%
VRU-VRU	112	137	82%
VRU-motorised	13	137	9%

Type of road user and minor lane-changing conflict type PET - Kunstlaan

	#	Total	
Lane-changing conflict	61	904	7%
Motorised-motorised	9	61	15%
VRU-VRU	46	61	75%
VRU-motorised	6	61	10%

Type of road user and minor rear-end conflict type PET - Kunstlaan

	#	Total	
Rear-end conflict	706	904	78%
Motorised-motorised	244	706	35%
VRU-VRU	462	706	65%
VRU-motorised	0	706	0%

Moderate accident with type of road user - PET Kunstlaan

Description	#	Total	%
Moderate accidents pedestrians and pedestrians	0	24	0%
Moderate accidents pedestrians and bicycles	5	24	21%
Moderate accidents pedestrians and motorised	5	24	21%
Moderate accidents bicycles and bicycles	2	24	8%
Moderate accidents bicycles and motorised	5	24	21%
Moderate accidents motorised vehicles	7	24	29%

Type of road user and moderate crossing conflict type PET - Kunstlaan

	#	Total	
Crossing conflicts	15	24	63%
Motorised-motorised	1	15	7%
VRU-VRU	6	15	40%
VRU-motorised	8	15	53%

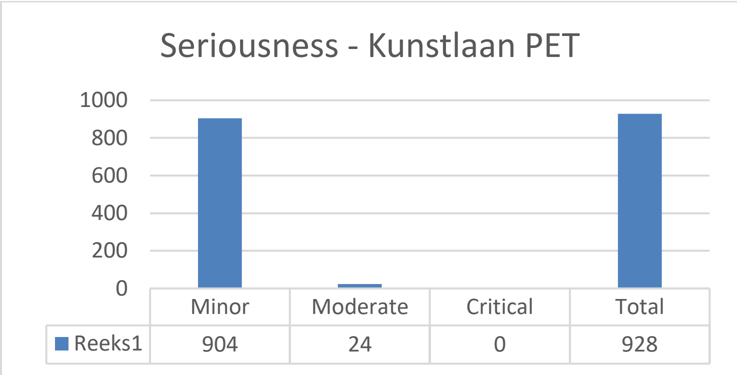
Type of road user and moderate lane-changing conflict type PET - Kunstlaan

	#	Total	
Lane-changing conflict	2	24	8%
Motorised-motorised	0	2	0%
VRU-VRU	0	2	0%
VRU-motorised	2	2	100%

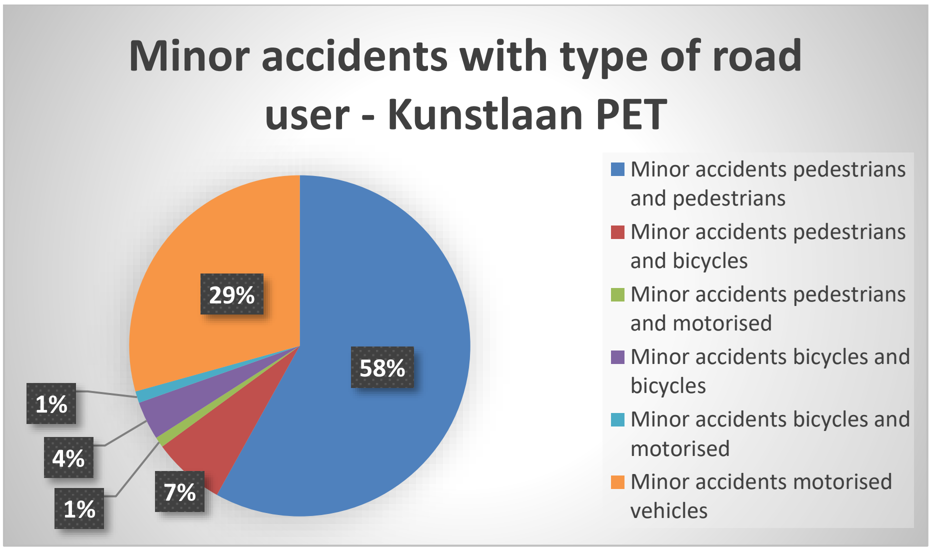
Type of road user and moderate rear-end conflict type PET - Kunstlaan

	#	Total	
Rear-end conflict	7	24	29%
Motorised-motorised	6	7	86%
VRU-VRU	1	7	14%
VRU-motorised	0	7	0%

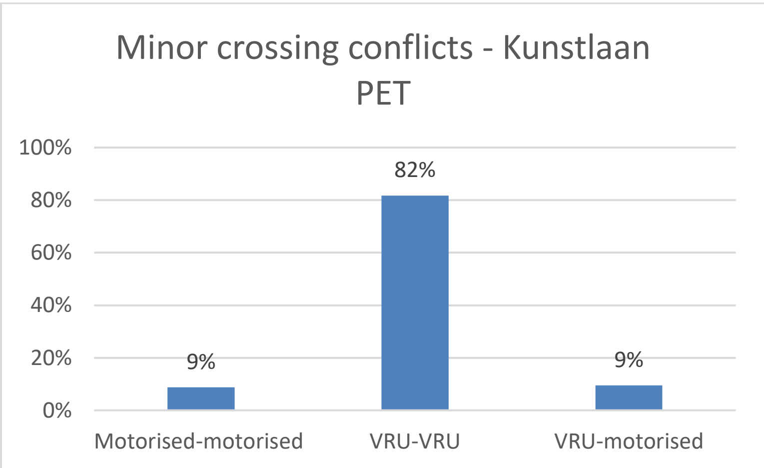
Seriousness Kunstlaan



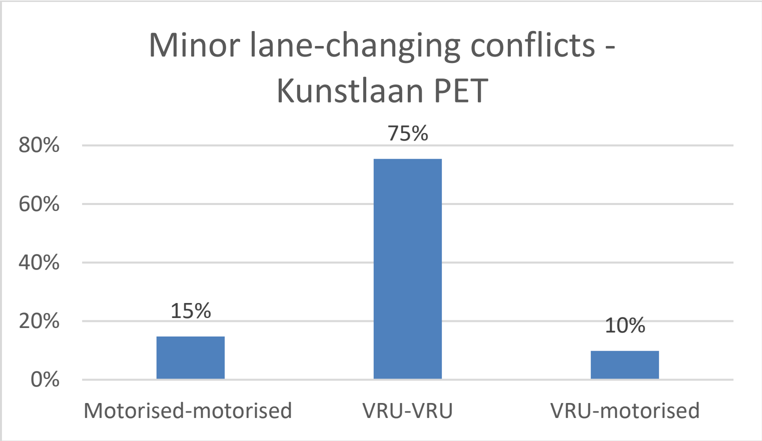
Minor accidents with type of road user PET - Kunstlaan



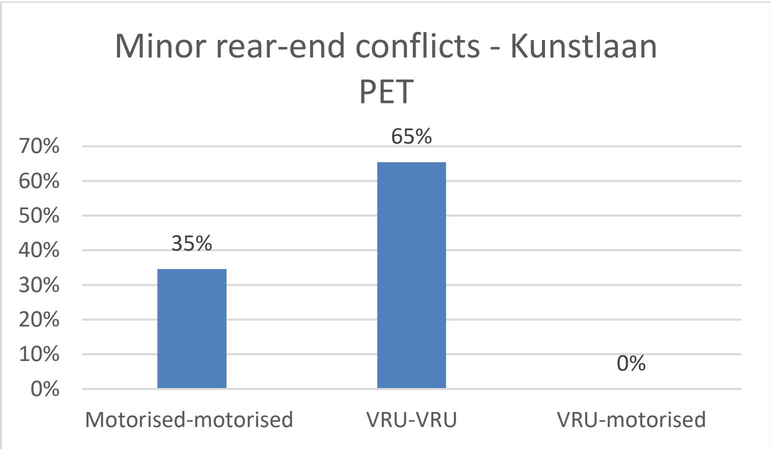
Type of road user and minor crossing conflict type PET - Kunstlaan



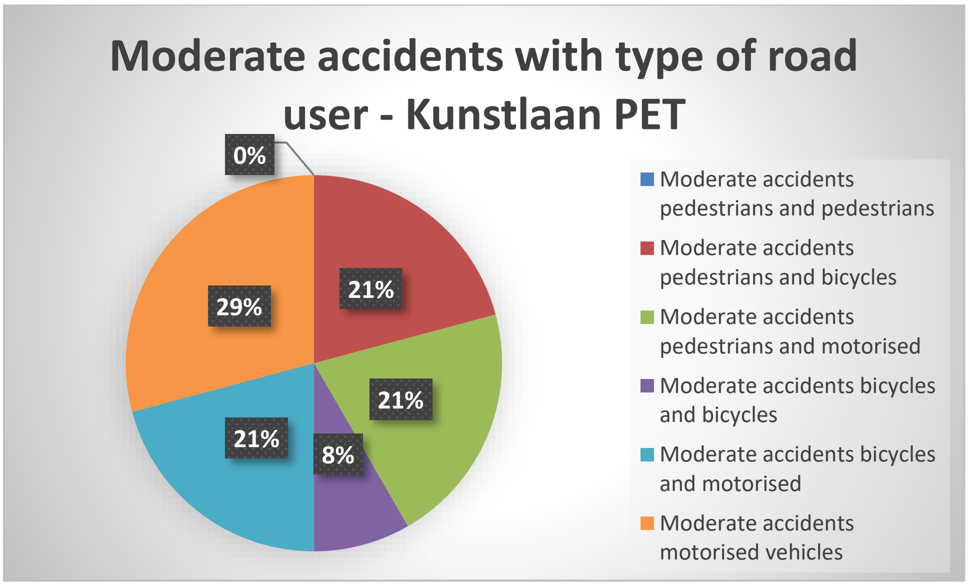
Type of road user and minor lane-changing conflict type PET - Kunstlaan



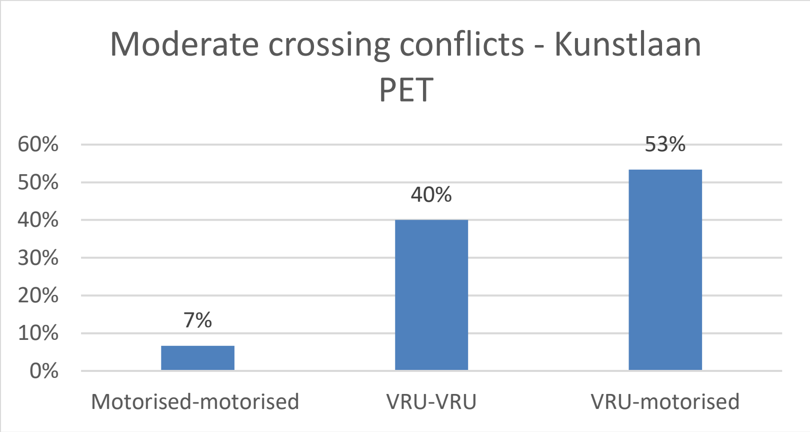
Type of road user and minor rear-end conflict type PET - Kunstlaan



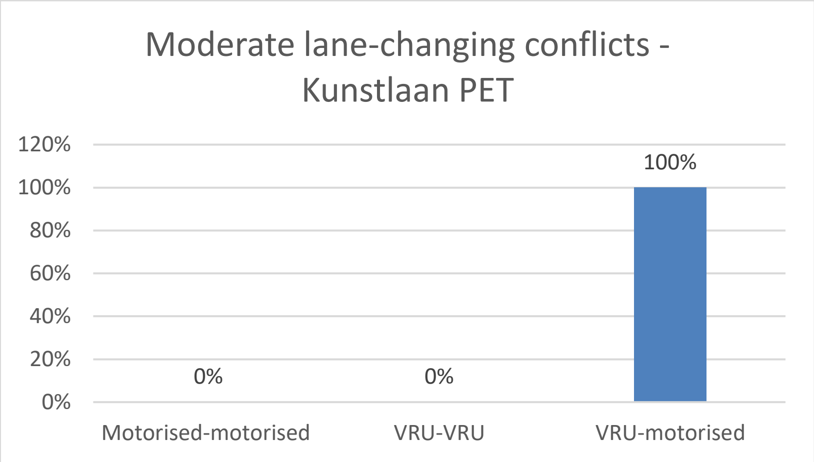
Moderate accident with type of road user PET - Kunstlaan



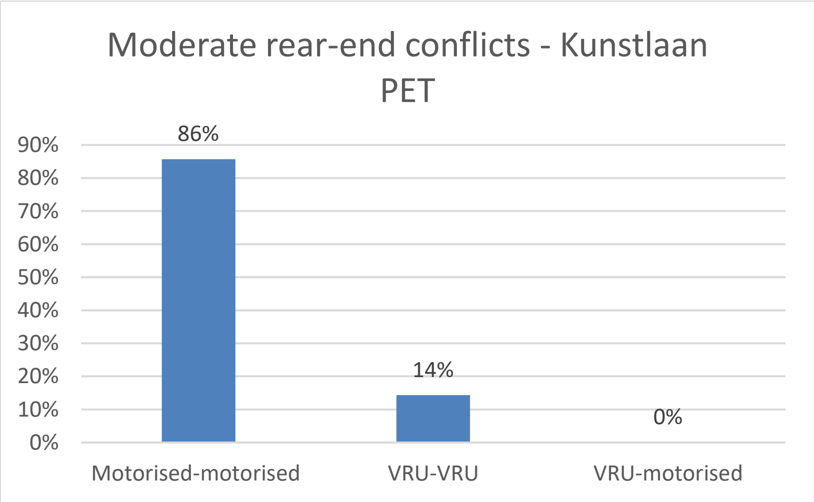
Type of road user and moderate crossing conflict type PET - Kunstlaan



Type of road user and moderate lane-changing conflict type PET - Kunstlaan



Type of road user and moderate rear-end conflict type PET - Kunstlaan



Seriousness TTC Kunstlaan

% Seriousness	
Minor	581
Moderate	152
Critical	7
Total	740

Minor accidents with type of road user TTC - Kunstlaan

Description	#	Total	%
Minor accidents pedestrians and pedestrians	0	581	0%
Minor accidents pedestrians and bicycles	115	581	20%
Minor accidents pedestrians and motorised	81	581	14%
Minor accidents bicycles and bicycles	36	581	6%
Minor accidents bicycles and motorised	41	581	7%
Minor accidents motorised vehicles	308	581	53%

Type of road user and minor crossing conflict type TTC - Kunstlaan

	#	Total	%
Crossing conflicts	200	581	34%
Motorised-motorised	82	200	41%
VRU-VRU	55	200	28%
VRU-motorised	63	200	32%

Type of road user and minor lane-changing conflict type TTC - Kunstlaan

	#	Total	%
Lane-changing conflict	138	581	24%
Motorised-motorised	62	138	45%
VRU-VRU	26	138	19%
VRU-motorised	50	138	36%

Type of road user and minor rear-end conflict type TTC - Kunstlaan

	#	Total	%
Rear-end conflict	243	581	42%
Motorised-motorised	164	243	67%
VRU-VRU	70	243	29%
VRU-motorised	9	243	4%

Moderate accident with type of road user - TTC Kunstlaan

Description	#	Total	%
Moderate accidents pedestrians and pedestrians	0	152	0%
Moderate accidents pedestrians and bicycles	10	152	7%
Moderate accidents pedestrians and motorised	10	152	7%
Moderate accidents bicycles and bicycles	4	152	3%
Moderate accidents bicycles and motorised	29	152	19%
Moderate accidents motorised vehicles	99	152	65%

Type of road user and moderate crossing conflict type TTC - Kunstlaan

	#	Total	%
Crossing conflicts	55	152	36%
Motorised-motorised	27	55	49%
VRU-VRU	10	55	18%
VRU-motorised	18	55	33%

Type of road user and moderate lane-changing conflict type TTC - Kunstlaan

	#	Total	%
Lane-changing conflict	57	152	38%
Motorised-motorised	38	57	67%
VRU-VRU	1	57	2%
VRU-motorised	18	57	32%

Type of road user and moderate rear-end conflict type TTC - Kunstlaan

	#	Total	
Rear-end conflict	40	152	26%
Motorised-motorised	34	40	85%
VRU-VRU	3	40	8%
VRU-motorised	3	40	8%

Critical accident with type of road user - TTC Kunstlaan

Description	#	Total	%
Critical accidents pedestrians and pedestrians	0	7	0%
Critical accidents pedestrians and bicycles	0	7	0%
Critical accidents pedestrians and motorised	0	7	0%
Critical accidents bicycles and bicycles	0	7	0%
Critical accidents bicycles and motorised	5	7	71%
Critical accidents motorised vehicles	2	7	29%

Type of road user and critical crossing conflict type TTC - Kunstlaan

	#	Total	%
Crossing conflicts	5	7	71%
Motorised-motorised	1	5	20%
VRU-VRU	0	5	0%
VRU-motorised	4	5	80%

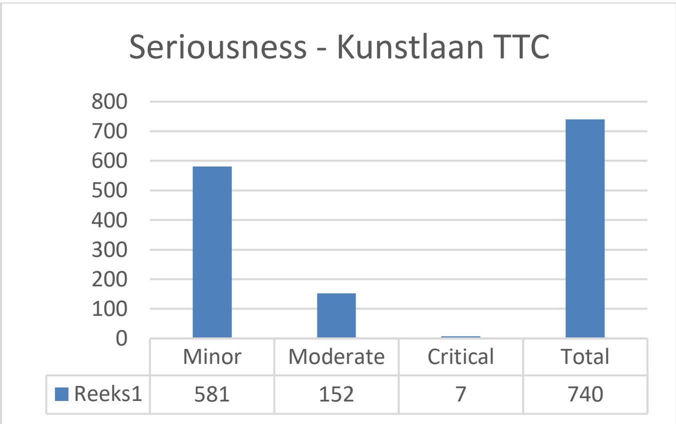
Type of road user and critical lane-changing conflict type TTC - Kunstlaan

	#	Total	
Lane-changing conflict	1	7	14%
Motorised-motorised	0	1	0%
VRU-VRU	0	1	0%
VRU-motorised	1	1	100%

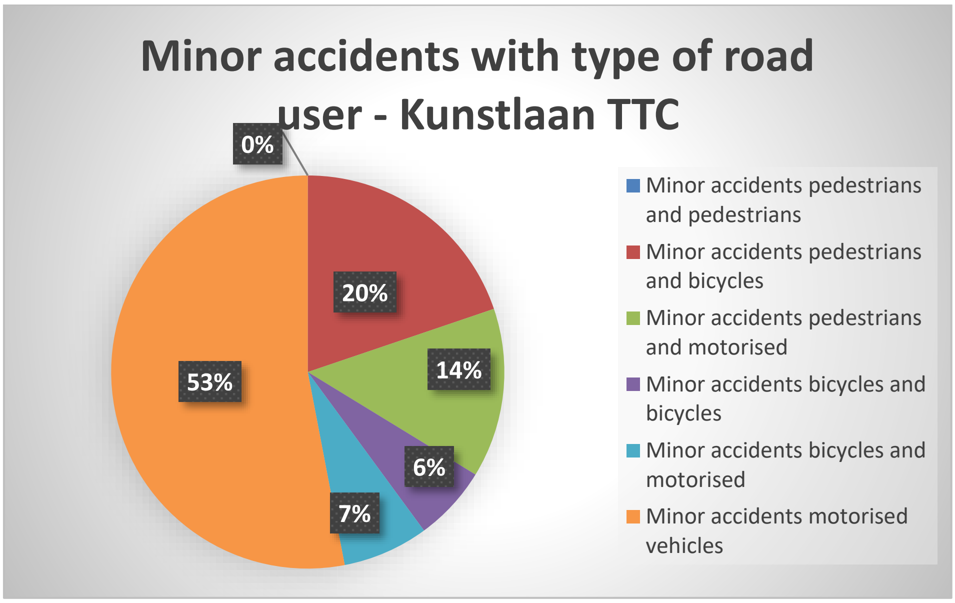
Type of road user and critical rear-end conflict type TTC - Kunstlaan

	#	Total	%
Rear-end conflict	1	7	14%
Motorised-motorised	1	1	100%
VRU-VRU	0	1	0%
VRU-motorised	0	1	0%

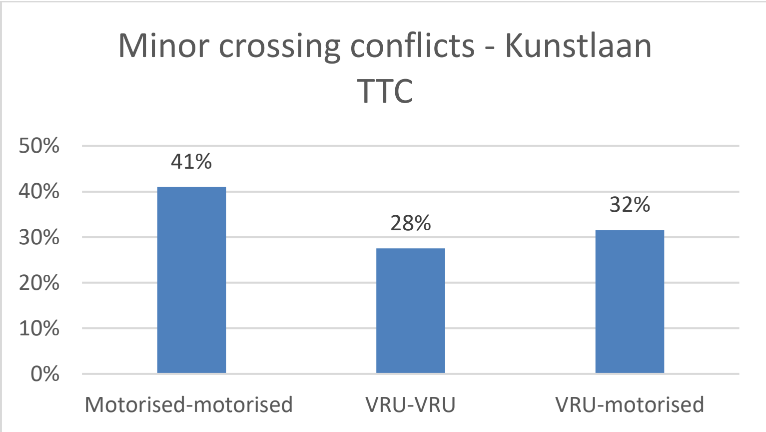
Seriousness Kunstlaan



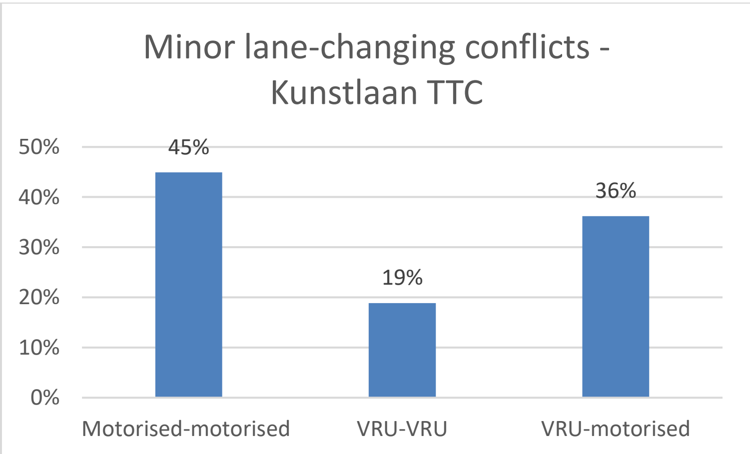
Minor accidents with type of road user TTC - Kunstlaan



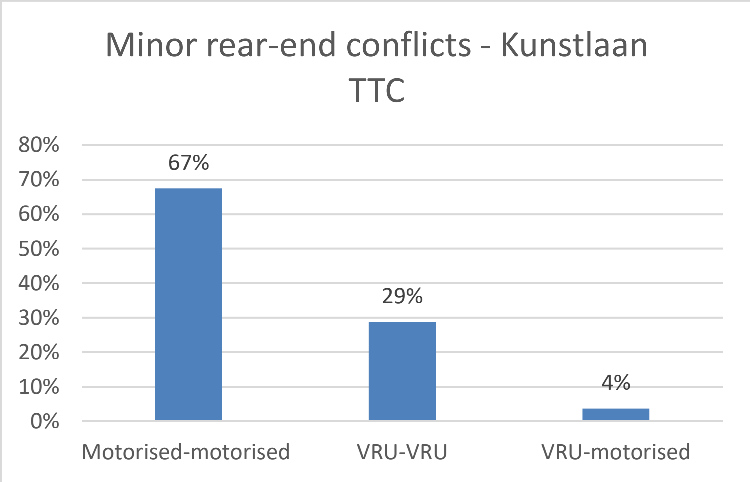
Type of road user and minor crossing conflict type TTC - Kunstlaan



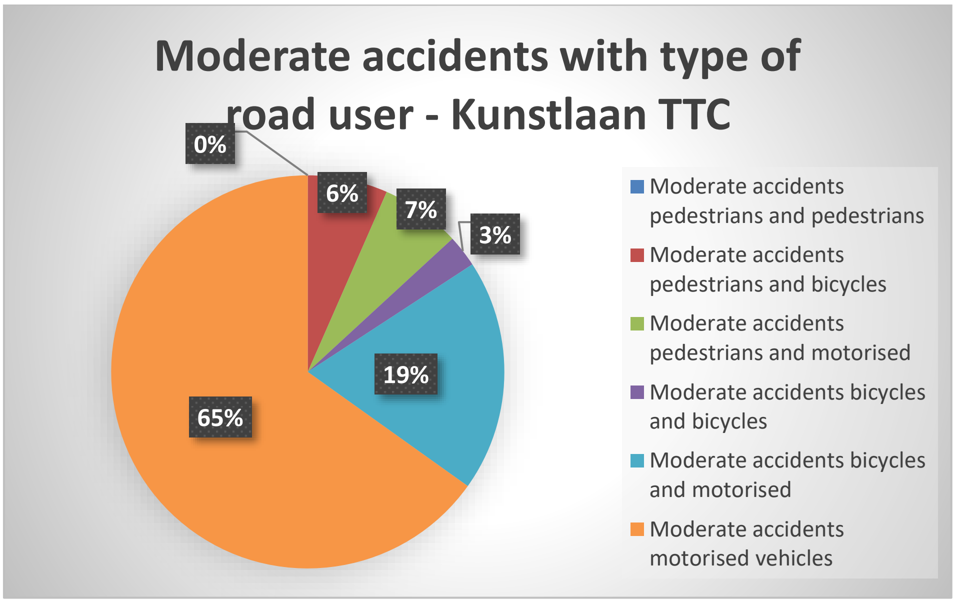
Type of road user and minor lane-changing conflict type TTC - Kunstlaan



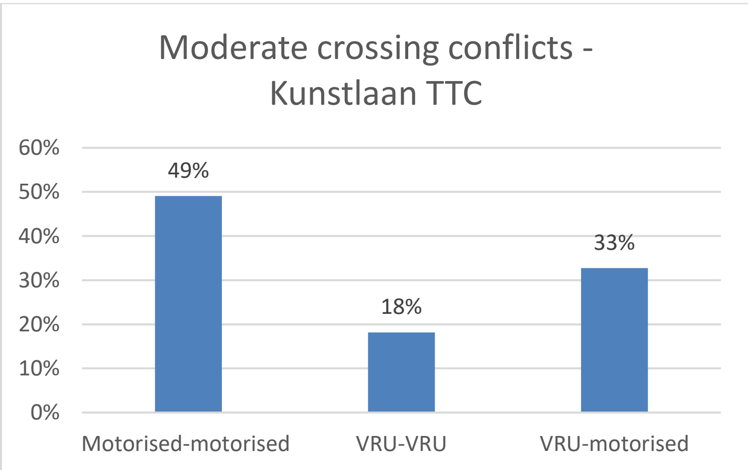
Type of road user and minor rear-end conflict type TTC - Kunstlaan



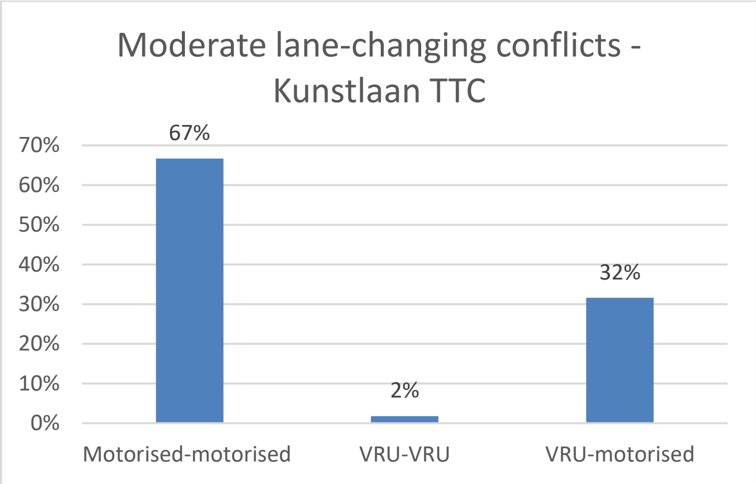
Moderate accident with type of road user TTC - Kunstlaan



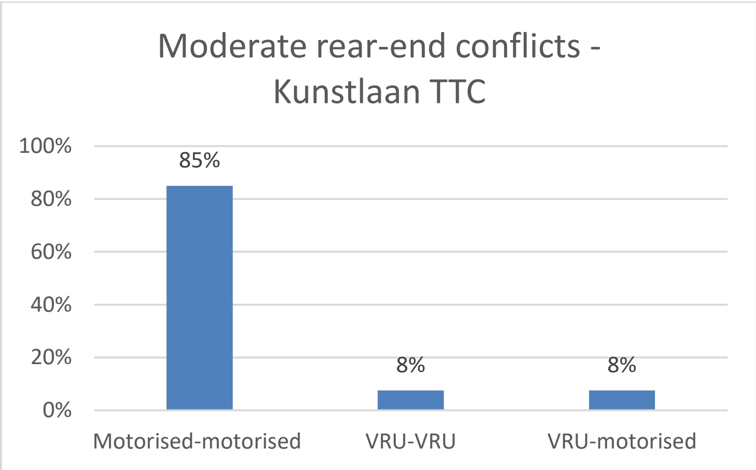
Type of road user and moderate crossing conflict type TTC - Kunstlaan



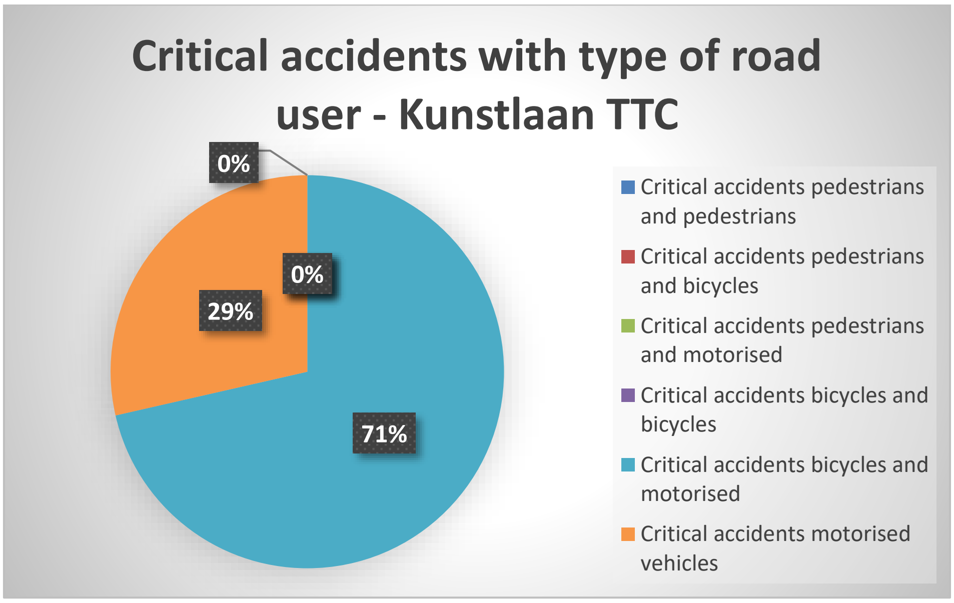
Type of road user and moderate lane-changing conflict type TTC - Kunstlaan



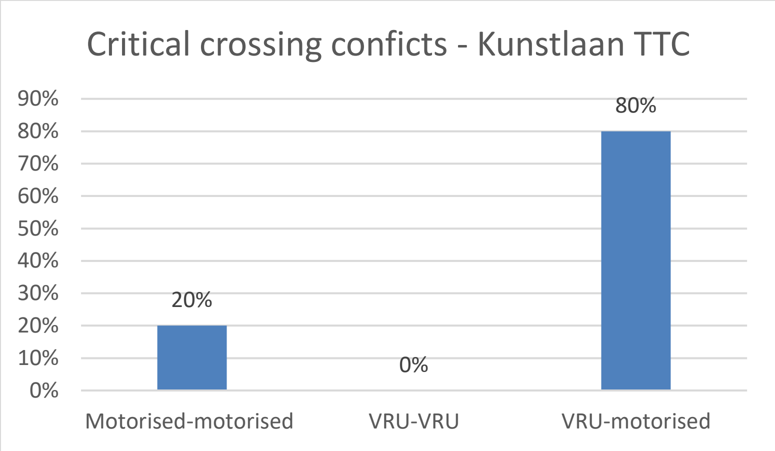
Type of road user and moderate rear-end conflict type TTC - Kunstlaan



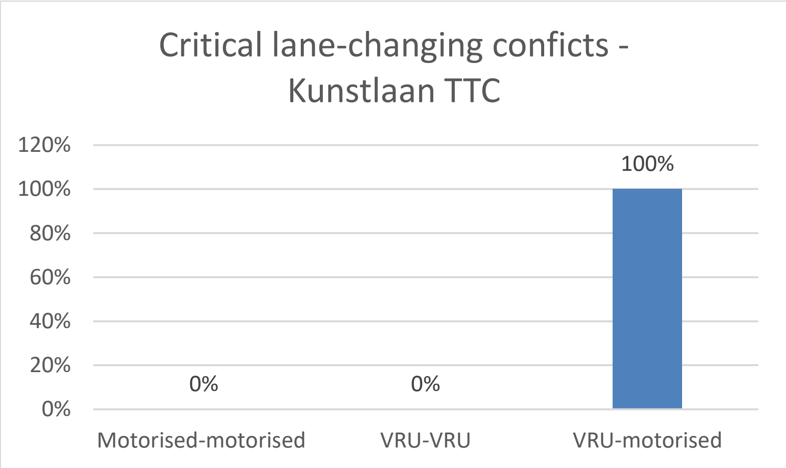
Critical accidents with type of road user TTC - Kunstlaan



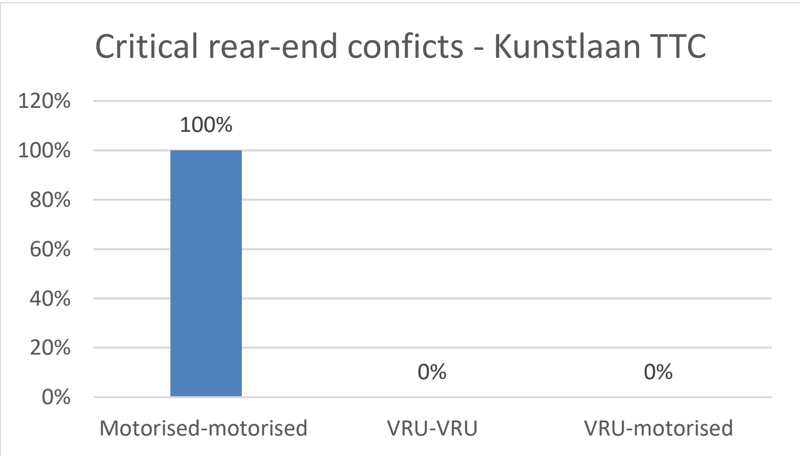
Type of road user and critical crossing conflict type TTC - Kunstlaan



Type of road user and critical lane-changing conflict type TTC - Kunstlaan



Type of road user and critical rear-end conflict type TTC - Kunstlaan



8.5 Data Sint-Truidersteenweg and Luikersteenweg

Seriousness PET Sint-Truidersteenweg

% Seriousness	
Minor	905
Moderate	23
Critical	0
Total	928

Minor accidents with type of road user PET - Sint-Truidersteenweg

Description	#	Total	%
Minor accidents pedestrians and pedestrians	53	905	6%
Minor accidents pedestrians and bicycles	127	905	14%
Minor accidents pedestrians and motorised	3	905	0%
Minor accidents bicycles and bicycles	327	905	36%
Minor accidents bicycles and motorised	10	905	1%
Minor accidents motorised vehicles	385	905	43%

Type of road user and minor crossing conflict type PET - Sint-Truidersteenweg

	#	Total	
Crossing conflicts	122	905	13%
Motorised-motorised	1	122	1%
VRU-VRU	119	122	98%
VRU-motorised	2	122	2%

Type of road user and minor lane-changing conflict type PET - Sint-Truidersteenweg

	#	Total	
Lane-changing conflict	79	905	9%
Motorised-motorised	1	79	1%
VRU-VRU	74	79	94%
VRU-motorised	4	79	5%

Type of road user and minor rear-end conflict type PET - Sint-Truidersteenweg

	#	Total	
Rear-end conflict	704	905	78%
Motorised-motorised	383	704	54%
VRU-VRU	314	704	45%
VRU-motorised	7	704	1%

Moderate accident with type of road user - PET Sint-Truidersteenweg

Description	#	Total	%
Moderate accidents pedestrians and pedestrians	0	23	0%
Moderate accidents pedestrians and bicycles	8	23	35%
Moderate accidents pedestrians and motorised	3	23	13%
Moderate accidents bicycles and bicycles	7	23	30%
Moderate accidents bicycles and motorised	5	23	22%
Moderate accidents motorised vehicles	0	23	0%

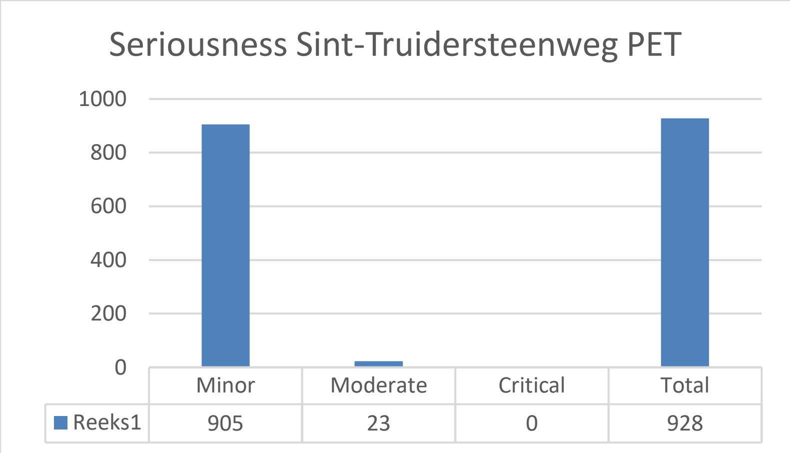
Type of road user and moderate crossing conflict type PET - Sint-Truidersteenweg

	#	Total	
Crossing conflicts	16	23	70%
Motorised-motorised	0	16	0%
VRU-VRU	14	16	88%
VRU-motorised	2	16	13%

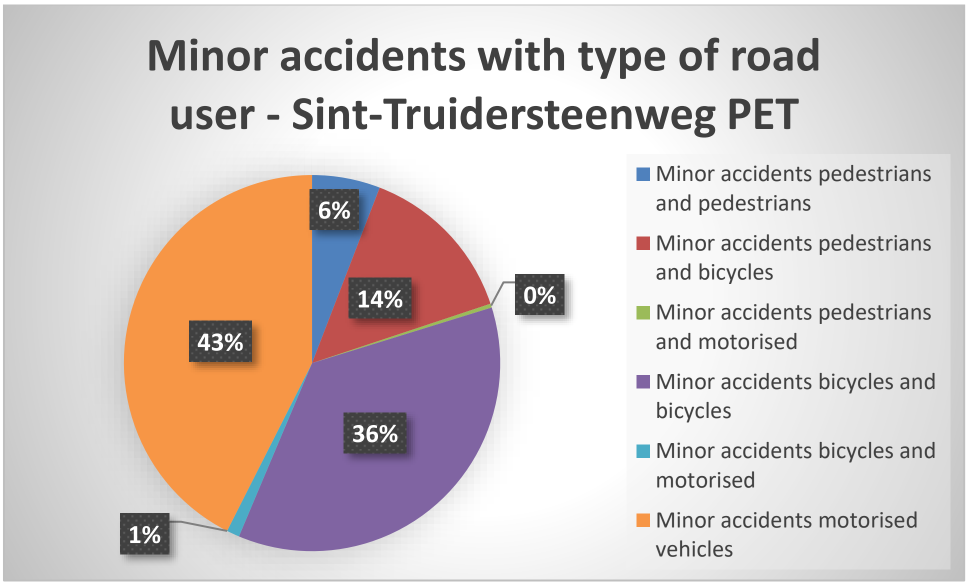
Type of road user and moderate lane-changing conflict type PET - Sint-Truidersteenweg

	#	Total	
Lane-changing conflict	7	23	30%
Motorised-motorised	0	7	0%
VRU-VRU	1	7	14%
VRU-motorised	6	7	86%

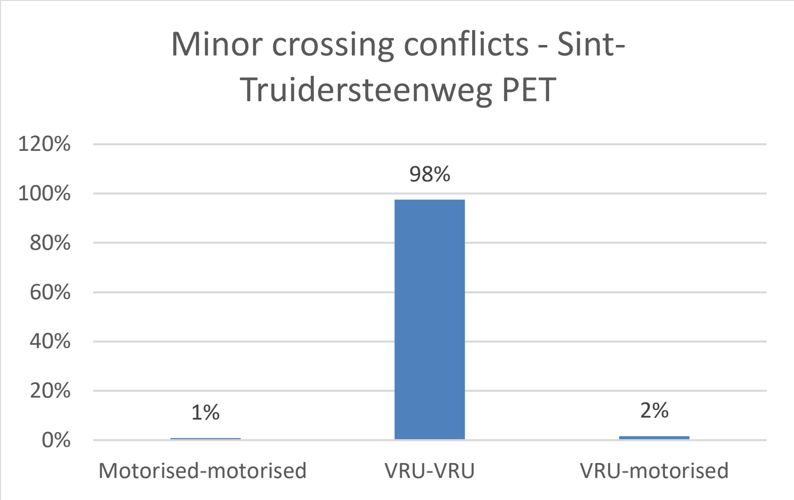
Seriousness Sint-Truidersteenweg



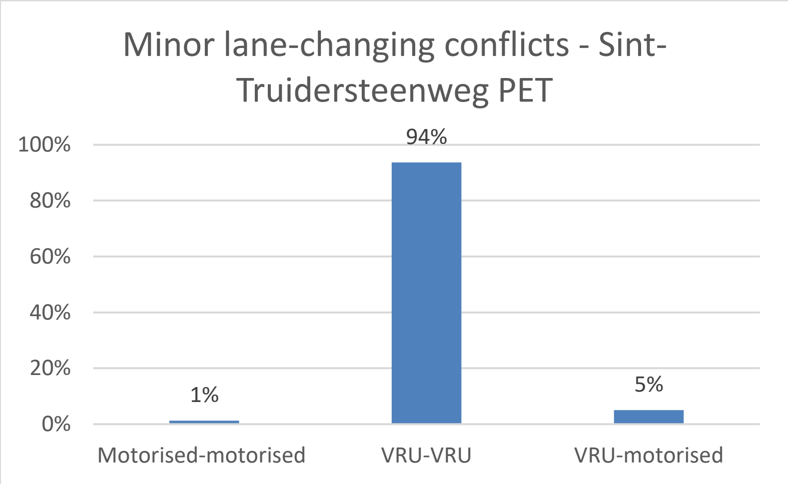
Minor accidents with type of road user PET - Sint-Truidersteenweg



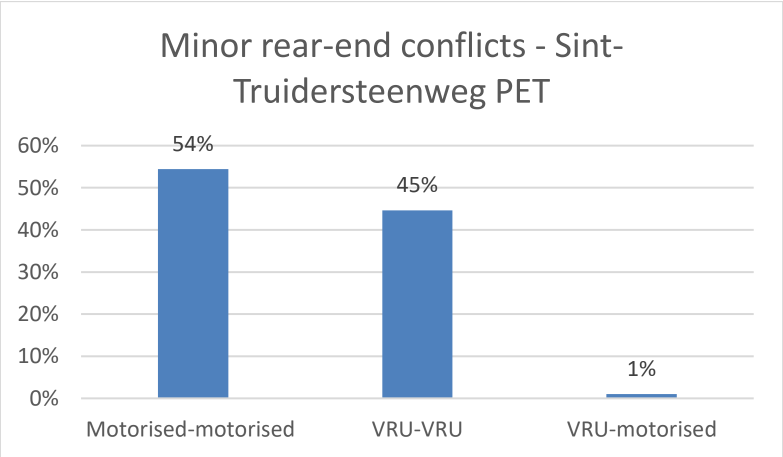
Type of road user and minor crossing conflict type PET - Sint-Truidersteenweg



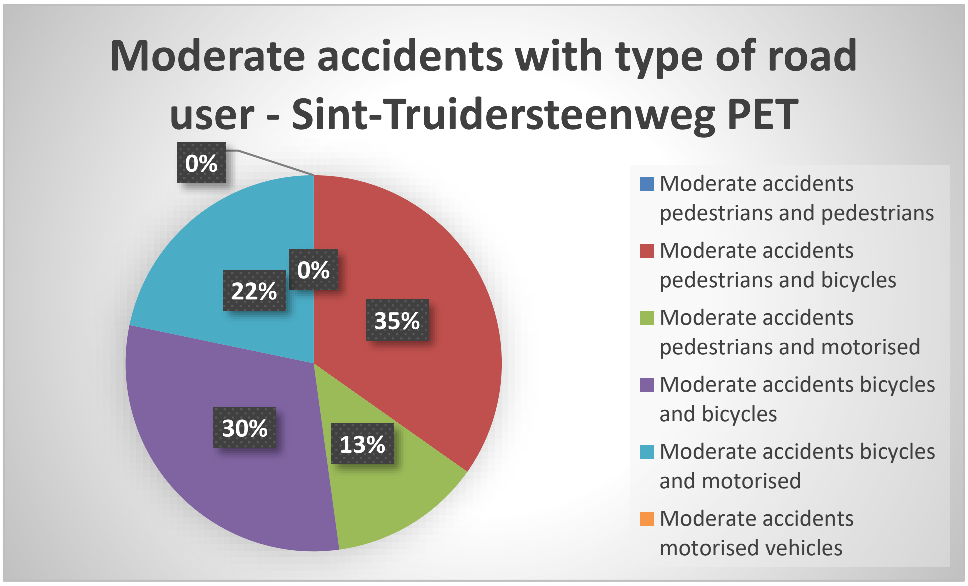
Type of road user and minor lane-changing conflict type PET - Sint-Truidersteenweg



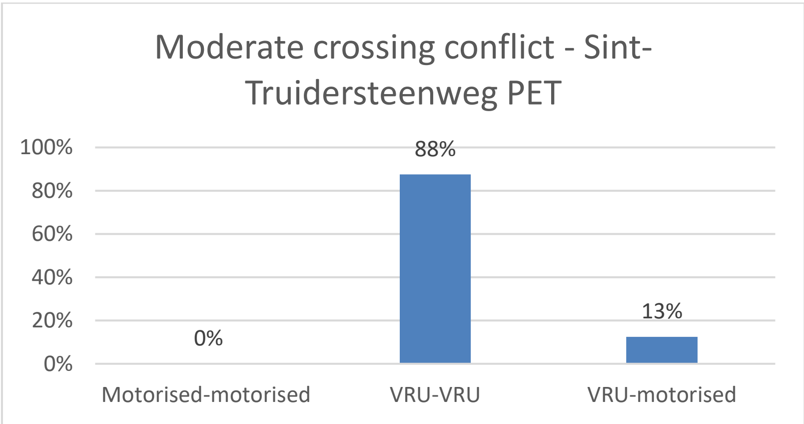
Type of road user and minor rear-end conflict type PET - Sint-Truidersteenweg



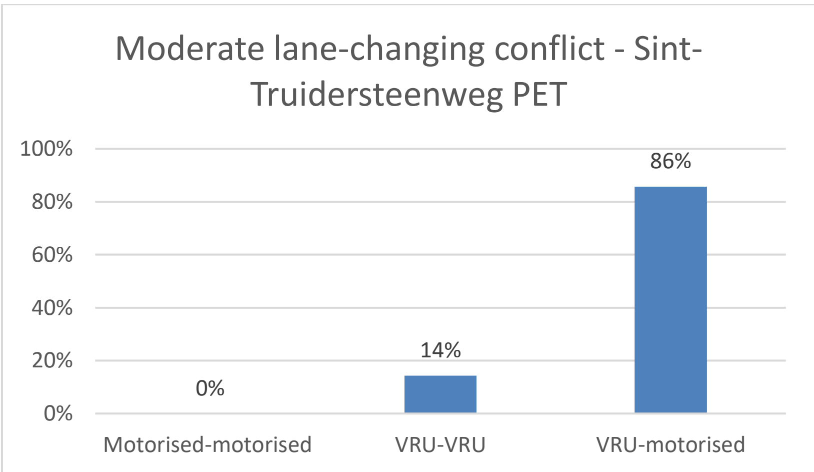
Moderate accident with type of road user PET - Sint-Truidersteenweg



Type of road user and moderate crossing conflict type PET - Sint-Truidersteenweg



Type of road user and moderate lane-changing conflict type PET - Sint-Truidersteenweg



Seriousness TTC Sint-Truidersteenweg

% Seriousness	
Minor	713
Moderate	168
Critical	3
Total	884

Minor accidents with type of road user TTC - Sint-Truidersteenweg

Description	#	Total	%
Minor accidents pedestrians and pedestrians	0	713	0%
Minor accidents pedestrians and bicycles	152	713	21%
Minor accidents pedestrians and motorised	59	713	8%
Minor accidents bicycles and bicycles	335	713	47%
Minor accidents bicycles and motorised	115	713	16%
Minor accidents motorised vehicles	52	713	7%

Type of road user and minor crossing conflict type TTC - Sint-Truidersteenweg

	#	Total	%
Crossing conflicts	141	713	20%
Motorised-motorised	4	141	3%
VRU-VRU	81	141	57%
VRU-motorised	56	141	40%

Type of road user and minor lane-changing conflict type TTC - Sint-Truidersteenweg

	#	Total	%
Lane-changing conflict	247	713	35%
Motorised-motorised	2	247	1%
VRU-VRU	137	247	55%
VRU-motorised	108	247	44%

Type of road user and minor rear-end conflict type TTC - Sint-Truidersteenweg

Rear-end conflict	325	713	46%
Motorised-motorised	46	325	14%
VRU-VRU	269	325	83%
VRU-motorised	10	325	3%

Moderate accident with type of road user - TTC Sint-Truidersteenweg

Description	#	Total	%
Moderate accidents pedestrians and pedestrians	0	168	0%
Moderate accidents pedestrians and bicycles	11	168	7%
Moderate accidents pedestrians and motorised	22	168	13%
Moderate accidents bicycles and bicycles	34	168	20%
Moderate accidents bicycles and motorised	88	168	52%
Moderate accidents motorised vehicles	13	168	8%

Type of road user and moderate crossing conflict type TTC - Sint-Truidersteenweg

	#	Total	%
Crossing conflicts	72	168	43%
Motorised-motorised	0	72	0%
VRU-VRU	33	72	46%
VRU-motorised	39	72	54%

Type of road user and moderate lane-changing conflict type TTC - Sint-Truidersteenweg

	#	Total	%
Lane-changing conflict	84	168	50%
Motorised-motorised	5	84	6%
VRU-VRU	11	84	13%
VRU-motorised	68	84	81%

Type of road user and moderate rear-end conflict type TTC - Sint-Truidersteenweg

Rear-end conflict	12	168	7%
Motorised-motorised	8	12	67%
VRU-VRU	1	12	8%
VRU-moto Grafiekgebied	3	12	25%

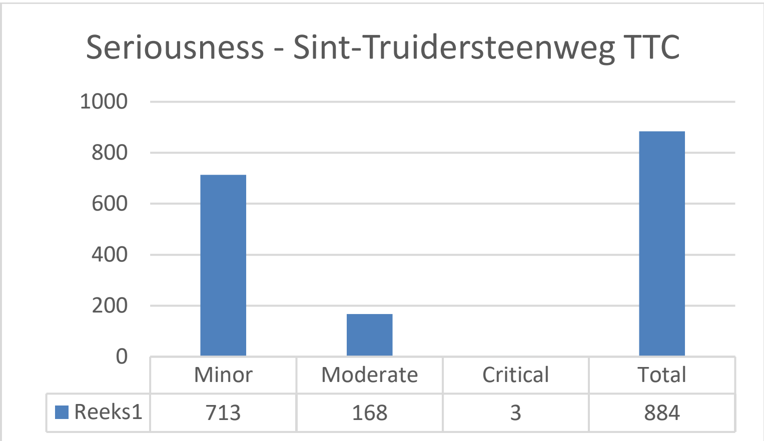
Critical accidents with type of road user TTC - Sint-Truidersteenweg

Description	#	Total	%
Critical accidents pedestrians and pedestrians	0	3	0%
Critical accidents pedestrians and bicycles	0	3	0%
Critical accidents pedestrians and motorised	0	3	0%
Critical accidents bicycles and bicycles	0	3	0%
Critical accidents bicycles and motorised	1	3	33%
Critical accidents motorised vehicles	2	3	67%

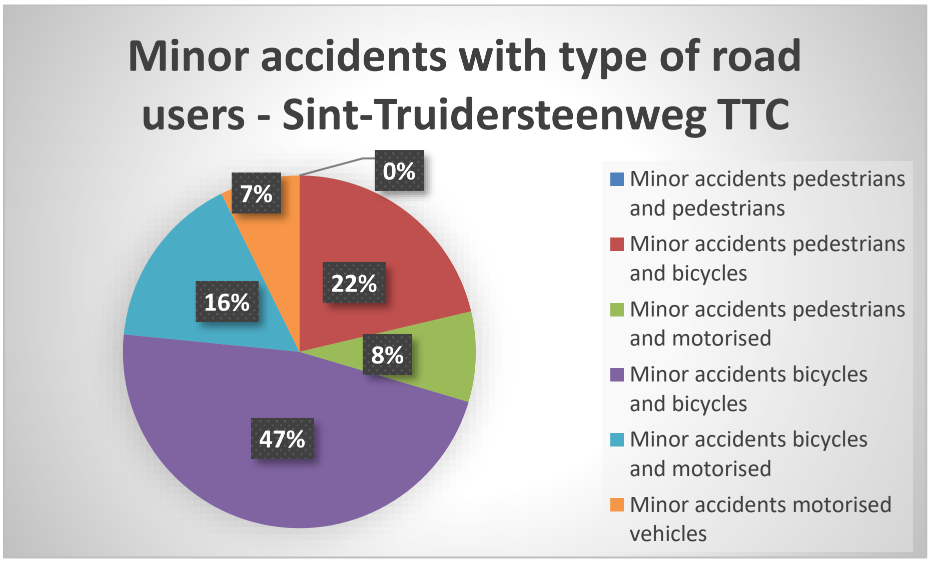
Type of road user and critical lane-changing conflict type TTC - Sint-Truidersteenweg

	#	Total	%
Lane-changing conflict	3	3	100%
Motorised-motorised	2	3	67%
VRU-VRU	0	3	0%
VRU-motorised	1	3	33%

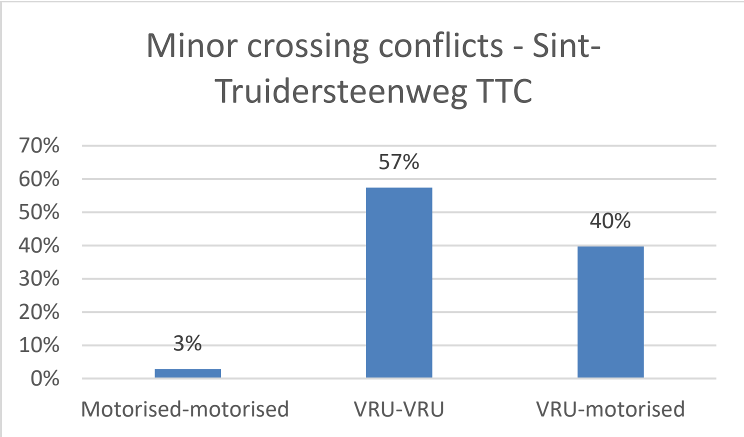
Seriousness Sint-Truidersteenweg



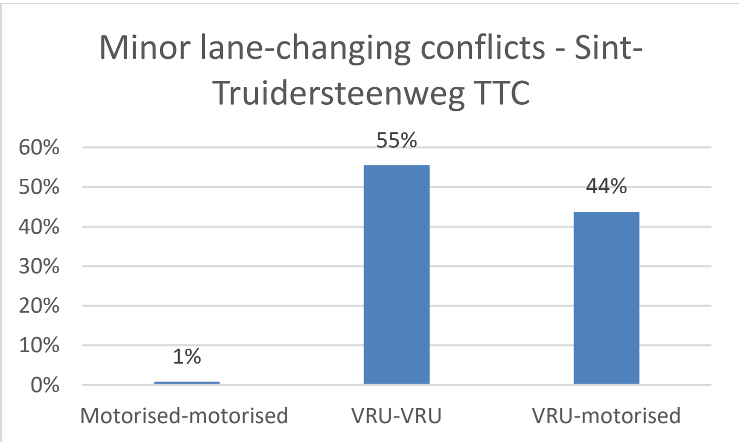
Minor accidents with type of road user TTC - Sint-Truidersteenweg



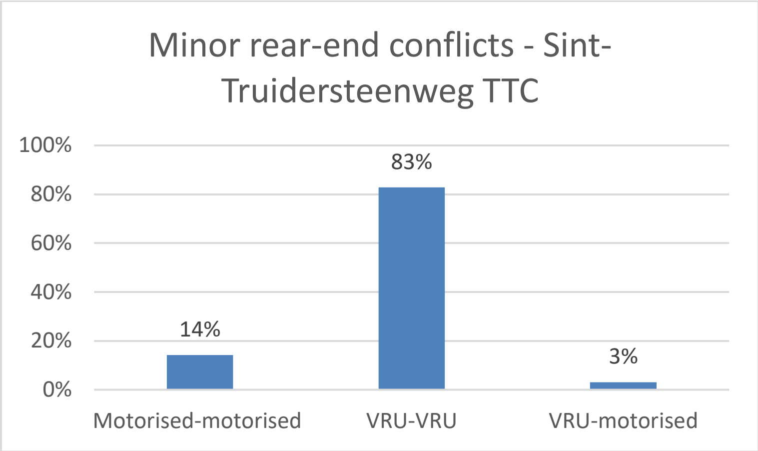
Type of road user and minor crossing conflict type TTC - Sint-Truidersteenweg



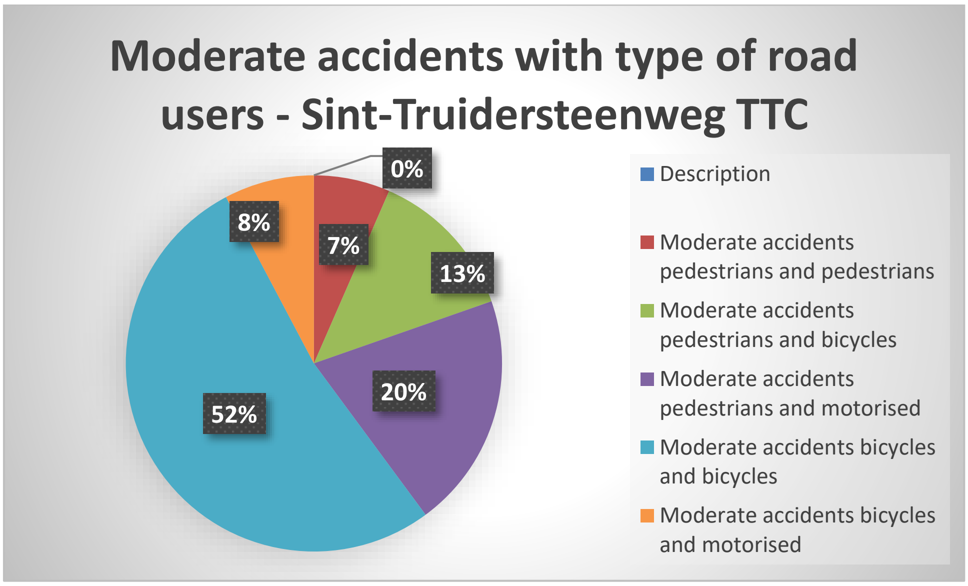
Type of road user and minor lane-changing conflict type TTC - Sint-Truidersteenweg



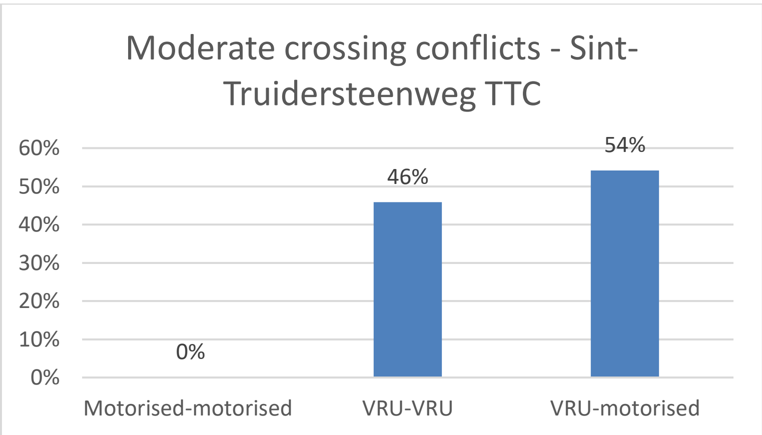
Type of road user and minor rear-end conflict type TTC - Sint-Truidersteenweg



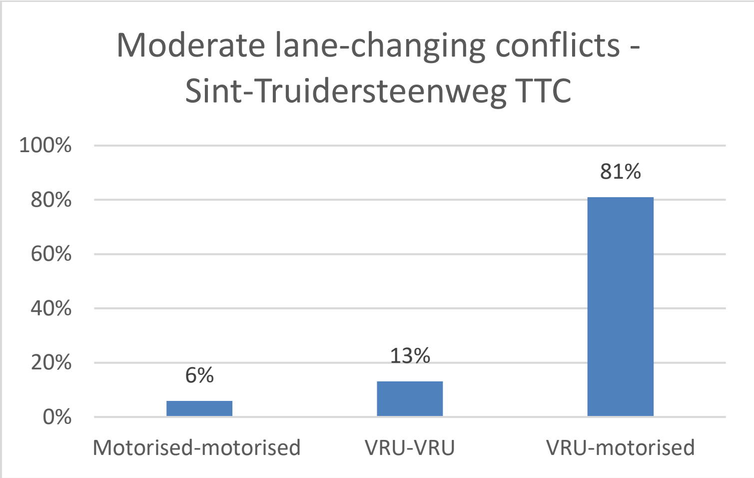
Moderate accident with type of road user TTC - Sint-Truidersteenweg



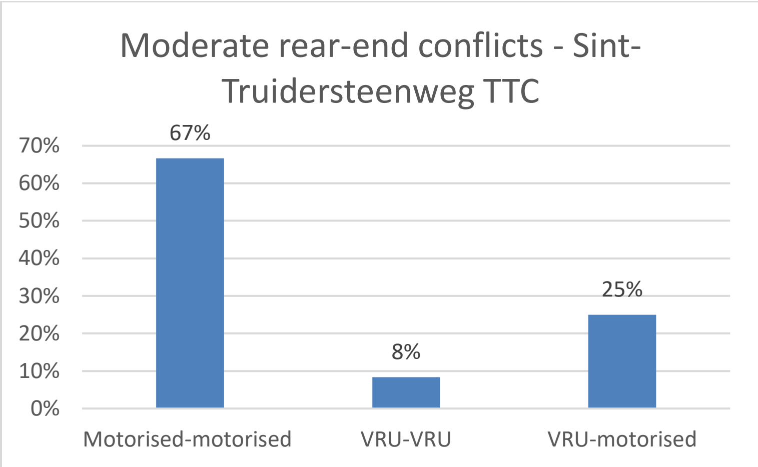
Type of road user and moderate crossing conflict type TTC - Sint-Truidersteenweg



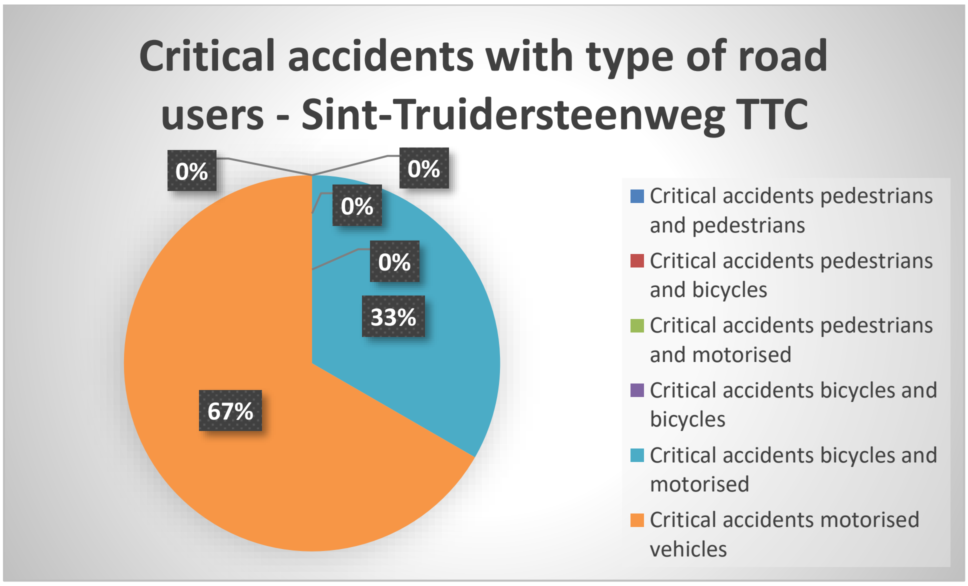
Type of road user and moderate lane-changing conflict type TTC - Sint-Truidersteenweg



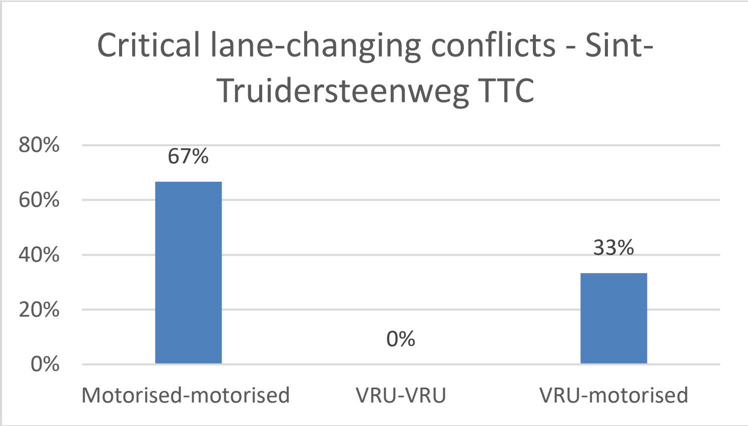
Type of road user and moderate rear-end conflict type TTC - Sint-Truidersteenweg



Critical accidents with type of road user TTC - Sint-Truidersteenweg



Type of road user and minor lane-changing conflict type TTC - Sint-Truidersteenweg


Critical lane-changing conflicts - Sint-Truidersteenweg TTC
80%
60%
40%
20%
0%
67%
0%
33%
Motorised-motorised
VRU-VRU
VRU-motorised