CHALMERS
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Safety assessment and improvements for urban intersections

A study about traffic safety in Gothenburg

Master's thesis in the Master's Programme Infrastructure and Environmental Engineering

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Master's Thesis ACEX30-19-20
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A person passing an intersection at a zebra crossing against a red light. The intersection is located at Skånegatan, Gothenburg. Author's own copyright.

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ABSTRACT

Traffic safety is an important aspect when planning and designing for new intersections in the urban environment. To reduce the number of accidents and increase the traffic safety there are several parameters to consider, including the road design, the vehicle and the road users. The aim of the study was to find connections between the design of the intersections and the traffic safety by investigating the relationship between flow and safety. Also, to give safety improvement suggestions to prevent the most common types of accidents in Gothenburg. In order to reach the aim an investigation of 20 4-legged intersections in Gothenburg was conducted. Information about the occurred accidents with injuries was received from Strada for a period of ten years. The accident statistics and the flow in each intersection were used to investigate the correlation between flow and safety. It was found that a linear trend in the correlation could be seen, especially if removing outliers. However, due to the uncertain correlation further studies regarding the relationship between flow and safety are needed.

The result from the study of the 20 investigated intersections in Gothenburg showed that the most common types of accidents occurring in the investigated intersections were of the type rear-end, crossing, pedestrian in collision with vehicle, bicycle in collision with vehicle and tram. These types of accidents were therefore in focus when presenting improvement suggestions. Improvements in the investigated intersections were mostly focused on increasing the awareness for the road users of the upcoming traffic situation. The types of accidents that occur in the investigated intersections are most often caused by the road users and not because of the design of the intersections. Therefore, it is mainly the behaviour of the road users that needs to be considered and not specifically the design of the existing intersections when considering what improvements that should be done for the investigated intersections.

Key words: traffic safety, four-legged intersections, Strada, injuries, accidents, safety improvements, flow

Säkerhetsbedömning och förbättringar för korsningar i staden

En studie kring trafiksäkerhet i Göteborg

Examensarbete inom masterprogrammet Infrastruktur och miljöteknik

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SAMMANFATTNING

En viktig aspekt för planering och utformning av nya korsningar i stadsmiljö är trafiksäkerhet. För att minska antalet olyckor och samtidigt öka trafiksäkerheten finns det flera parametrar som behöver tas i beaktning vilka innefattar vägens utformning, fordonen samt trafikanterna. Syftet med studien var att finna samband mellan korsningarnas utformning och trafiksäkerheten genom att studera förhållandet mellan flöde och säkerhet. Även förbättringsförslag togs fram för att förhindra de olyckor som främst sker i Göteborg. För att nå syftet med studien studerades 20 fyrvägskorsningar i Göteborg. Informationen från Strada om vilka olyckor med skador som har skett studerades för en tioårsperiod. Olycksstatistiken och flödet i alla korsningar användes till att undersöka korrelationen mellan flöde och säkerhet. Från detta sågs en trendlinje i korrelationen, särskilt när de punkterna med avvikande värden togs bort. Eftersom det var en oviss korrelation som sågs i förhållandet mellan flödet och säkerheten behövs fortsatta studier.

Resultatet av de 20 studerade korsningarna i Göteborg visade att de vanligaste olyckstyperna som sker var upphinnandeolyckor, korsningsolyckor, gående i kollision med fordon, cykel i kollision med fordon samt spårvagnsolyckor. Dessa olyckstyper var därför i fokus när förbättringsförslagen togs fram. Förbättringarna för de studerade korsningarna syftade främst till att uppmärksamma trafikanterna för den kommande trafiksituationen. Olyckstyperna som sker i de studerade korsningarna sker främst på grund av trafikanterna och inte på grund av korsningarnas utformning. Därför är det främst beteendet hos trafikanterna som behöver tas i beaktning och inte korsningarnas utformning när förbättringsförslag tas fram för de studerade korsningarna.

Nyckelord: trafiksäkerhet, fyrvägskorsningar, Strada, skador, olyckor, säkerhetsåtgärder, flöde

Contents

Preface

This was a Master's Thesis written at the Department of Architecture and Civil Engineering and the Division of Geology and Geotechnics at Chalmers University of Technology in Gothenburg. The project was done on behalf of Sigma Civil during the spring of 2019.

We would like to thank our advisor Alexander Hörnquist at Sigma Civil for his great help, support and advice throughout the project. We would also like to thank Fredrik Johnson and Sigma Civil, in general, for letting us work in their office and for including us in the organization. Finally, we want to thank our examiner Xiaobo Qu at Chalmers for supporting us throughout the project.

Gothenburg May 2019

Jenny Jansson & Caroline Nilsson

Notations

DICTIONARY

Accessibility	Tillgänglighet
Availability	Framkomlighet
Design	Utformning
Elevated intersection	Planskild korsning
Field study	Fältstudie
Give way	Väja
Offset intersection	Förskjuten korsning
Personal Data Act	Personuppgiftslagen
Private vehicle	Personbil
Public Access and Secrecy Act	Offentlighets- och sekretesslagen
Raised intersection	Upphöjd korsning
Rear-end accident	Upphinnandeolycka
Road users	Trafikanter
Rumble strips	Bullerremsor
Traffic accident	Vägtrafikolycka
Traffic environment	Vägtrafikmiljö
Traffic island	Refug
Traffic Regulation	Trafikförordningen
Turning vehicle	Avsvängande fordon
Unprotected road users	Oskyddade trafikanter
Vehicle traffic	Biltrafik
Zebra crossing	Övergångsställe

EXPRESSIONS AND ABBREVIATIONS

AADT	Annual Average Daily Traffic. The average traffic that daily passes the road.
Flow	Is the flow regarding the vehicles passing the intersection also called AADT.
NVDB	National road database from the Swedish Transport Administration
Strada	Swedish Traffic Accident Data Acquisition. A database that includes information about accidents for pedestrians, bikes and cars from the police and/or emergency hospitals in the traffic environment.
Vehicles	Meaning motorized vehicles and not bicycles
VGU	A Swedish abbreviation of a document called “Vägar och Gators Utformning” (Road and streets design) from the Swedish Transport Administration, containing regulations, descriptions and recommendations of modeling of roads and streets in Sweden.

AUTHORITIES

Ministry of Enterprise and Innovation	Näringsdepartementet
Swedish Municipalities and County Councils	Sveriges kommuner och landsting
Swedish Transport Administration	Trafikverket
Traffic and Public Transport Authority	Trafikkontoret, Göteborgs stad

1 Introduction

Sustainable development can be divided into three dimensions, environmental, social and economic development, where traffic safety is a part of the social sustainability (Swedish Transport Administration, 2018a). In 2015, the 17 global goals for sustainable development was adapted by the member states of the United Nations. These 17 goals are divided further into 169 goal targets and 230 indicators. From the sustainable development goals, it is shown that a sustainable society requires a sustainable transport system, where traffic safety is an important aspect. Traffic safety is especially involved in two of the goal targets. One of them includes that the number of global deaths and injuries from road traffic accidents should be halved by 2030. The other goal target is to provide access to safe, accessible, affordable and sustainable transport system for all road users.

Connecting to the sustainable development goals regarding safe roads and traffic, Sweden have an ambition called Vision Zero. Meaning that no one shall be killed or severely injured in traffic and that the design, function and use of the transport system shall be adapted to fulfill this objective (Government Offices of Sweden, 2016). During 2017 the number of fatal traffic accidents in Sweden were 253, which is a decrease from previous years (Swedish Transport Administration, 2018a). Even if the numbers have decreased since 1997 when Vision Zero was adapted, actions still need to be taken to reach the goal.

The city of Gothenburg expects that almost half a million more people will use the roads in the city in 2020 compared to 2010 (Traffic and Public Transport Authority, 2009). In the same timespan the goal for the city is that the severe injuries shall decrease from 300 to 75 and fewer than three fatal accidents. According to Strada it occurred 87 severe injuries and five fatal injuries in Gothenburg municipality during 2017. Which means that actions need to be done to reach the goal for the city before 2020.

Intersections are according to Abdel-Aty & Keller (2005) a common place for traffic accidents, which can be explained because of the several conflicting movements and countless different intersection design characteristics. In urban areas, accidents in intersections are the type of accident that contributes to the most fatal and severe injuries for vehicle drivers (Swedish Municipalities and County Councils, 2015b). There are many aspects that contribute to the accident frequency in intersections, but one of the main is considered to be the flow measured in AADT (Chen & Xie, 2016). An important factor to reach Vision Zero is to make sure that traffic safety is accounted for in early stages of planning the city, and that it has a high priority when planning and designing for a new area, as well as in maintenance of existing roads (Traffic and Public Transport Authority, 2009).

1.1 Aim

The aim of this report is to gain knowledge about traffic safety and road design and how they are connected. The aim is also to investigate the connection between flow and traffic accidents in urban intersections in Gothenburg. A literature study about the process when planning and designing intersections to be safe for all road users will be conducted. From literature and assessment of intersections in urban Gothenburg area, improvement suggestions for selected intersections will be given with focus on safety.

In order to reach the aim of the report following questions will be answered:

- Which parameters affect the traffic safety?
    - Is there a connection between road design and traffic safety?
- Is the accident frequency connected to the flow; does a higher flow result in more accidents/injuries?
- Which type of accidents is common to occur in urban intersections?
    - What improvements can be done?

1.2 Limitations

This study is limited to the geographical area of the city of Gothenburg where only urban intersections with the speed limit 50 km/h will be assessed. The study is limited to only consider 20 intersections that are 4-legged, where each leg of the intersection needs to be trafficked by at least one sort of motorized vehicle. Also, the data for the flow in each leg of the intersection need to be available. The flow for pedestrians and cyclists is not considered. Another limitation is that the accident statistics is taken for a period of 10 years.

The study is limited to evaluate the design of the intersections, flow and its correlation to traffic safety, meaning that external factors is not considered, such as temperature and weather conditions. Also, the cost of suggested improvements is not considered.

2 Literature review

A literature review was performed in order to gain knowledge about traffic safety and the design of intersections. The literature review included an introduction to traffic safety, current statistics regarding accidents as well as design and types of intersections. Also, general actions for safety improvements in intersections are presented.

2.1 Traffic Safety

Traffic safety can be defined as no one should be injured in traffic and it is therefore important to build and design roads to be safe for all road users in order to reduce the number of traffic accidents (Traffic and Public Transport Authority, 2009). A traffic accident is defined as an accident that has occurred on a road which is used for traffic with motorized vehicles, where at least one vehicle has been moving and resulted in at least one injured person (Ministry of Enterprise and Innovation, 2016).

Common causes of accidents are speeding, distracted driving, driving under the influence of drugs and/or alcohol, unsafe vehicle and unsafe road (World Health Organization, 2018). The speed has a big impact on the traffic safety, especially for the consequences of a collision (Swedish Municipalities and County Councils, 2008). The risk that a person is injured increases when the speed increases since the driver’s ability to react and prevent the accident decreases, Figure 1. The speed is, according to the Swedish Municipalities and County Councils (2015a), the core of the traffic safety and most of the work regarding traffic safety is oriented to reducing the speed.

Figure 1 *Collision force curve where the x-axis is the speed (km/h) and the y-axis the percentage of the risk of being killed in traffic. The first line represents pedestrians, the second side collision and the third a head-on collision (Swedish Municipalities and County Councils, 2008).*

For cyclists on the other hand, the design, maintenance and operation of the road are factors that have an impact on how many accidents that occur (Traffic and Public Transport Authority, 2009). Also, not wearing a helmet or a seatbelt is an influencing factor on how severe the injury is if an accident occurs (Swedish Transport Administration, 2018c).

2.1.1 Parameters affecting the traffic safety

There are several parameters that affect the traffic safety. Both external factors, the road, the behaviour of road users and the unprotected road users have an impact on how safe the road and traffic environment are. These parameters are presented and described in this part of the report.

2.1.1.1 The road

The design of the road can have a big impact on the road safety and should be designed so that it is safe for all road users (World Health Organization, 2018). Important factors to consider in order to reduce the risk of injuries in traffic includes the width of the road, footpaths, bicycling lanes, speed limit and safe zebra crossings.

A problem with the unsafe roads is that there has been too high speed limits relative to the safety standard of the road and/or the design may be unclear (Swedish Transport Administration, 2018c). For example, broad unseparated country roads with high speed limit (90 km/h) expose the road users for head-on collisions which are fatal. It is also common that the road users exceed the speed limit on this type of road since broader roads causes the drivers to increase the speed (Swedish Municipalities and County Councils, 2009).

The width of the road is also a factor that affect the safety of the road (Swedish Municipalities and County Councils, 2009). By reducing the width of the road, the number of injuries can be reduced since the drivers generally have a lower speed when the road is narrow. A decreased width of the road makes it safer for the pedestrians to cross the road and gives the road users a better overview of the situation. However, a narrower road gives less space in unexpected situations, for example when it is needed to give way for emergency vehicle. It may also affect the availability for the motorized vehicles which in turn can transfer the traffic to nearby roads. If the width is broader the space for cyclists increases which may increase their safety.

The road lightning reduces the risk of being injured in traffic when it is dark since it makes it easier to comprehend the traffic situation such as the road environment and other road users (Swedish Municipalities and County Councils, 2009). The lightning of the road is also a way of feeling safer in the traffic environment since it decreases the discomfort for the road users.

2.1.1.2 Speed limit

By reducing the speed limit on the state roads there is a potential to reduce the number of fatalities (Swedish Transport Administration, 2018c). Reducing the speed limit with 1 km/h can theoretically save 15 lives per year. Lower speed limits contribute to a higher safety, but it can at the same time lead to people not following the limits. It is the speed limit combined with other measures, such as camera surveillance, which ensures that the speed limit is followed.

According to the Swedish Transport Administration (2018c) it is more common that the road users keep the speed limit on the municipal roads. Since municipal roads most often are found in urban areas there are many factors, apart from the speed limit, that affects the speed such as width of the road, distance between the intersections and the presence of footpaths and street parking. To ensure that the speed limit is kept the road design can be altered with, among other, speed bumps, narrowing and change of road width. These implementations make it more natural to follow the speed limit.

2.1.1.3 Vehicle

The safety depending on the vehicle can be divided into two categories, crash safety and driving safety (Swedish Municipalities and County Councils, 2015a). The crash safety includes the protective characteristics the car has when the accident occurs, for example seatbelts, air-bags and headrest. The driving safety is the characteristics that helps to minimize the risk that an accident occurs such as the driver's sight and braking system. Newer vehicles may have important safety systems such as automatic emergency brake and exit warning. A safe vehicle also has a reminder of the seatbelt and an antiskid.

2.1.1.4 Public transport

Public transport in Gothenburg is mainly consisting of trams and buses. The number of injured persons involved in accidents with tram or bus is not a big group, but the severity level of the injuries is relatively high and has a high share of the fatal and severe injuries (Traffic and Public Transport Authority, 2009). The majority of the accidents involving public transport vehicles are in conflict with private vehicles, however it is the unprotected road users who are most severely injured. According to Swedish Municipalities and County Councils (2013) 85% of all injured public transport users are injured in connection to the tram and bus stop. The city of Gothenburg is therefore prioritizing, among other things, to design safe bus and tram stops and connections to them (Traffic and Public Transport Authority, 2009). There is also a share of those who are injured inside the tram or bus, which most often depends on heavy braking from the driver.

A majority of those who were injured by tram in Gothenburg were located close to the tram stop, the rest were injured at the track (Trivector, 2013). Many of the tram related accidents occur because the road users do not pay full attention to the traffic situation and therefore do not see the oncoming tram (Guerrieri, 2018). By having shared lanes, which is when tramway rail and vehicles are in the same lane, accidents can occur due to cyclists and motorcyclists losing their balance if their wheel moves in the tramway rail. Defects connected to the tramway rail are also a problem for cyclists and motorcyclists since the cracks can cause loss and worsen the conditions.

Trams are special in terms of give way, if nothing other is designated the tram has the right of way and all other transport modes must yield for it (Traffic and Public Transport Authority, 2017). The design around the tramway is therefore important to consider, for example zebra crossings over tramways should be avoided since it creates a false safety for the pedestrians since the tram does not have to yield for the pedestrians as other vehicles must.

Public transport buses are large vehicles and have a big turning radius which can lead to difficulties for the driver in the rear view, there is therefore a risk that a collision may occur with private vehicles and unprotected road users who are on the side of the bus (Traffic and Public Transport Authority, 2009).

2.1.1.5 Unprotected road users

Pedestrian and bicycle passages over roads are locations where the unprotected road users will cross the road (Swedish Municipalities and County Councils, 2013). These passages are often regulated by road signs for zebra crossings or give way. The regulation has an influence on the availability for the pedestrians and cyclists, but not for the traffic safety. By having these signs the accident pattern changes, but the risk does not. Since it is common for drivers to not follow the traffic rule to give way for pedestrians at a zebra crossing it is a hidden risk for accidents.

There are three factors that affect the unprotected road users at a zebra crossing which affects the risk of being injured (Swedish Municipalities and County Councils, 2013). These are the speed of the vehicles, the traffic flow and the length of the zebra crossing. To decide whether the situation is safe enough for the pedestrians to cross the road or not is easier when the speed is lower, the zebra crossing is smaller or if there is less traffic at the road (Swedish Transport Administration, 2004).

2.1.1.6 Human factors

It is not only the outer conditions that matters for the safety on the roads, the road users have an impact as well. A person driving under the influence of drugs and/or alcohol is a dangerous driver (Swedish Transport Administration, 2018b). When using alcohol and drugs while driving the eyesight deteriorate, the reaction time gets slower and the attention decreases. Therefore, by driving under the influence of drugs and/or alcohol the risk of a crash increases (World Health Organization, 2018).

Pedestrians and motorcyclists that are under the influence of alcohol have a greater risk to die in traffic than other road users (Swedish Transport Administration, 2018c). In most of the cases where a fatal injury has occurred it is the road user himself/herself that has been influenced of alcohol or drugs, this also includes the unprotected road users.

Distracted driving is also common for persons behind the wheel and leads to impaired driving and thereby a greater risk of accident (World Health Organization, 2018). One of the most common types of distracted driving is using a mobile phone while driving. Using a mobile phone is a growing safety issue and makes it, among other things, hard to stay in the correct lane and to keep the correct following distances.

2.1.1.7 Sight

The road users must have an overview of the area in order to observe and identify if there are any obstacles, Figure 2 (Swedish Transport Administration, 2004). Increased sight makes it easier for the road users to get an overview of the traffic situation and time to make decisions in an early stage if there is any danger upcoming (Swedish Municipalities and County Councils, 2009). Obstacles that can occur on the road includes (Swedish Transport Administration, 2004):

- Other road users, for example meeting, crossing or rear-end, which needs to be seen in order to interact with.
- Obstacles on the road that are needed to be seen to slow down or give way for.
- Traffic devices, for example traffic signals, road signs or road markings.
- Obstacles close to the road that can affect the sight in, for example, intersections.

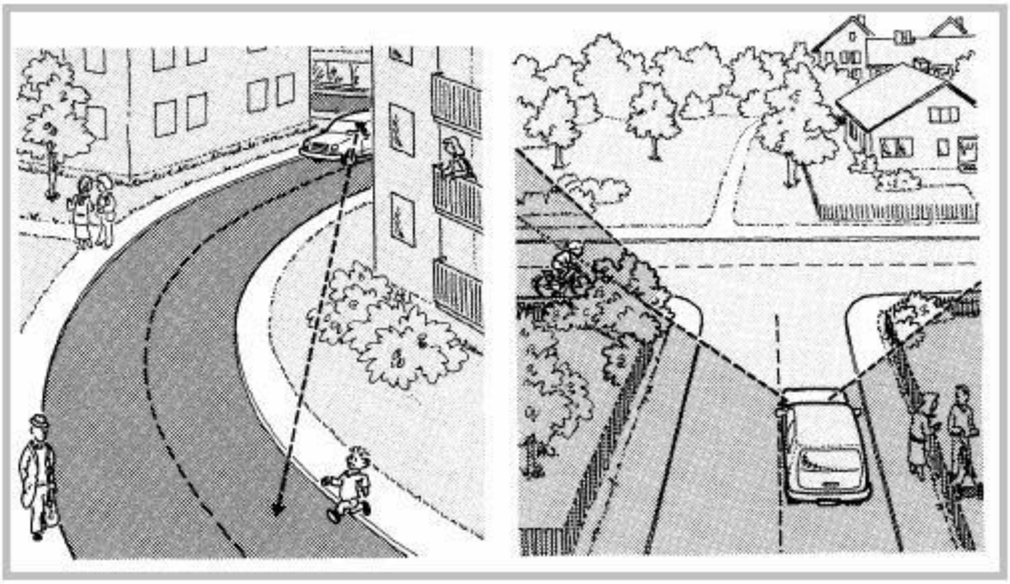

Figure 2 Example of good sight in the road area (Swedish Transport Administration, 2004).

The sight distances that the road are dimensioned for are based on that the drivers, that follow the speed limit, shall have time and possibility to stop on a wet road (Swedish Municipalities and County Councils, 2009).

2.1.1.8 Stop distance

The stop distance is the distance a driver needs to have to manage to stop the vehicle in time before an obstacle (Swedish Transport Administration, 2004). The stop distance is divided into reaction distance and braking distance. The reaction distance is the distance that the vehicle travel, with constant speed, during the time the driver sees the obstacle, reacts and brakes (Swedish Transport Agency, 2017). The braking distance is the distance for the vehicle from that point when the driver brakes to the point when the vehicle stands still. In low speeds the reaction distance is most of the stop distance but when the speed increases the braking distances increases.

2.1.1.9 External factors

External factors, for example the weather, are factors that affect the traffic safety but are not something that can be engineered in the work with traffic safety (Swedish Transport Administration, 2018c). Other factors such as age of the population and the economic situation affects the modes of transportation which in turn have an influence on fatalities and injured persons in traffic. The age of the population affects the traffic safety since different ages chooses different modes of transportation. They are also showing different behaviours in how great risks they are willing to take in traffic.

The weather can have a large impact on the traffic for short periods of time and on limited locations as at downpour or slip. According to Swedish Transport Administration (2018c) it is hard to investigate how much impact such temporary and local weather phenomena has on traffic safety. During winter season it has been seen that winter road conditions and low temperature cause reduced traffic and lower speeds. Winters with much snowfall leads to severe single accidents since there are a large amount of snow ending up in the roadside.

According to Swedish Transport Administration (2018c) there is a connection between the number of fatalities in traffic and the economic development. A decline in the economy is often followed by a decrease of the number of fatalities. This may be due to a declining travel during a recession and changes in the way people travel.

2.2 Connection between flow and safety

Traffic flow is considered to be the most powerful variable when constructing accident predicting models, and particularly intersection accident models (Ferreira & Couto, 2013). These models attempt to show how many accidents that may occur in different traffic situations. Models to predict the safety performance can be developed either with or without other inputs than the flow. Analyses performed in Sweden show that for the motorized vehicle users, the accident quota increases with an increased flow (Hagring, 2000). The connection between flow and accidents for unprotected road users is more complex. A higher flow of motorized vehicles increases the risk for pedestrians, while for cyclists the connection is not coherent. On the other hand, the accident quota decreases for pedestrians and cyclists when the flow of pedestrians and cyclists respectively increases.

If increasing the traffic volume while other factors are kept same, the relationship between the increased traffic and the increased number of accidents are not linear according to Swedish Municipalities and County Councils (2013). For example, if the traffic volume increases by 10%, the average number of accidents increases by 9%, but it is not confirmed if the severity level of the accident changes.

2.3 Traffic accidents

Traffic accidents occur in the traffic environment, these accidents are often a measure for traffic safety and are therefore important when considering changes in the road system. Statistics for Sweden and Gothenburg are presented in following section.

2.3.1 Fatal and severe traffic accidents in Sweden

The most common fatal accidents in traffic environment in Sweden are the single accidents with vehicles (Swedish Transport Administration, 2018c). The second most common fatal accident is meeting and overtaking accidents. Single accidents with vehicles are a type of accident that still increases in the road network. A single accident can for example be a collision with a tree.

There is also a difference between the municipal and the state road network (Swedish Transport Administration, 2018c). On the municipal roads most of the fatal injuries occurred between pedestrians and motorized vehicles. On the state road, on the other hand, the accidents where the most fatal injuries occurred were single accidents with motorized vehicles. Regardless the road operator, most accidents with fatal injuries occur on roads with the speed limit 70-90 km/h.

By comparing the municipal and state roads and the road users that are severely injured a difference between the roads can be noted (Swedish Transport Administration, 2018c). On the state road the drivers are more common to be injured and on the municipal road it is the cyclists. Therefore, it is the cyclists and persons in private vehicles that are most common to be severely injured. Out of those who are severe injured on a bicycle, moped or motorbike it is most common to be injured in a single accident while for the drivers at least half of the accidents are rear-end and crossing accidents. Among drivers, neck damages are the most common injury regardless of the degree of injury.

Many of those who are severely injured in the road transport system are pedestrians that have fallen over, but this is a type of accident that is not considered as a traffic accident since no vehicle has been involved (Swedish Transport Administration, 2018c). These types of accidents are most common during winter.

2.3.2 Traffic accidents in Gothenburg

For the last 10 years, information about traffic accidents and injured persons in Gothenburg can be found in Strada. A total of 35 020 persons were injured in traffic in Gothenburg municipality during January 1, 2008, to December 31, 2017. Out of those injuries there were 72 fatalities and 588 severe injuries.

According to Strada the two most common fatalities in Gothenburg are single accidents with vehicles and pedestrians in collision with a vehicle, Figure 3. Considering the severe accidents, the most common accident was single accidents with bicycle. According to Traffic and Public Transport Authority (2009) the elderly are overrepresented in fatal traffic accidents and every third of the deceased were over 65 years old. This is not because this group is exposed for more accidents, but because the injuries tend to get more severe with age. Analyses also show that many of the fatal and severe injured persons have driven unlawfully and that only one third of the fatal accidents could have been prevented. In this category it is the young men that are overrepresented and are challenging the system by driving too fast, not wearing safety belt and/or driving under the influence of alcohol and/or drugs.

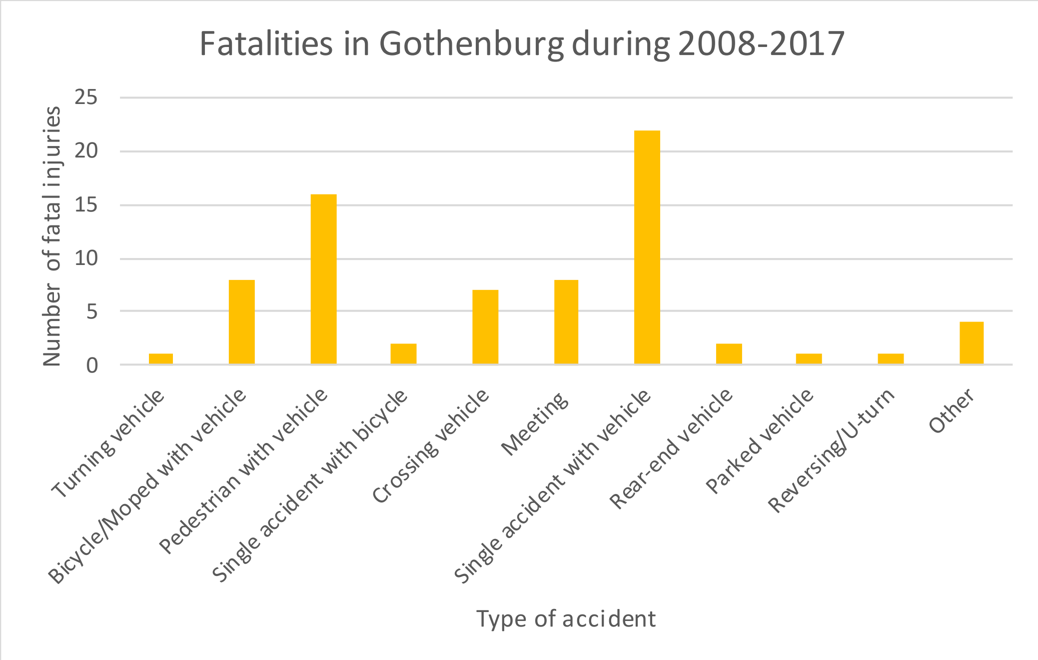

Figure 3 Number of fatalities in Gothenburg during 10 years. The figure is based on information from Strada. Author's own copyright.

2.4 Design of intersections

Traditionally, the design of roads and streets are based on capacity, mobility and safety (Pande & Wolshon, 2016). The goal with the design of an intersection is that the impression of the situation shall be so simple, structured and logical that the behaviour of the user is natural and thereby also safe (Swedish Transport Administration, 2004). Therefore, in this Section different types of intersections are described followed by actions for safety improvements.

2.4.1 Types of intersections

Intersections can be 3-legged or more, where the risk of accidents are in average up to two times bigger in a 4-legged intersection than in a 3-legged intersection (Swedish Transport Administration, 2018d). Therefore 4-legged intersections can be divided into two 3-legged intersections, called an offset intersection, Figure 4. This type of intersection is a better option in terms of traffic safety compared to a 4-legged intersection. Furthermore, the legs in an intersection are divided into primary and secondary roads, where the primary road is the major road or prioritized as a major road (Swedish Transport Administration, 2004). The secondary road is then the joining road, which is not primary.

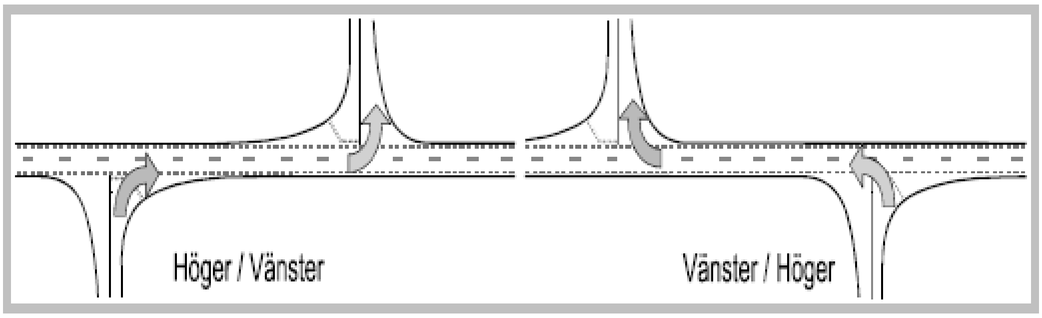

Figure 4 *Example of the design of an offset intersection, either right/left (höger/vänster) or left/right (vänster/höger) (Swedish Transport Administration, 2004).*

From the guideline document VGU from Swedish Transport Administration (2004) intersections are divided into two categories, smaller intersections and larger intersections. The intersection types are thereafter divided into subcategories, Figure 5. The smaller intersections are regulated either with priority of the right or right-of-way with or without stop signs (Swedish Transport Administration, 2004).

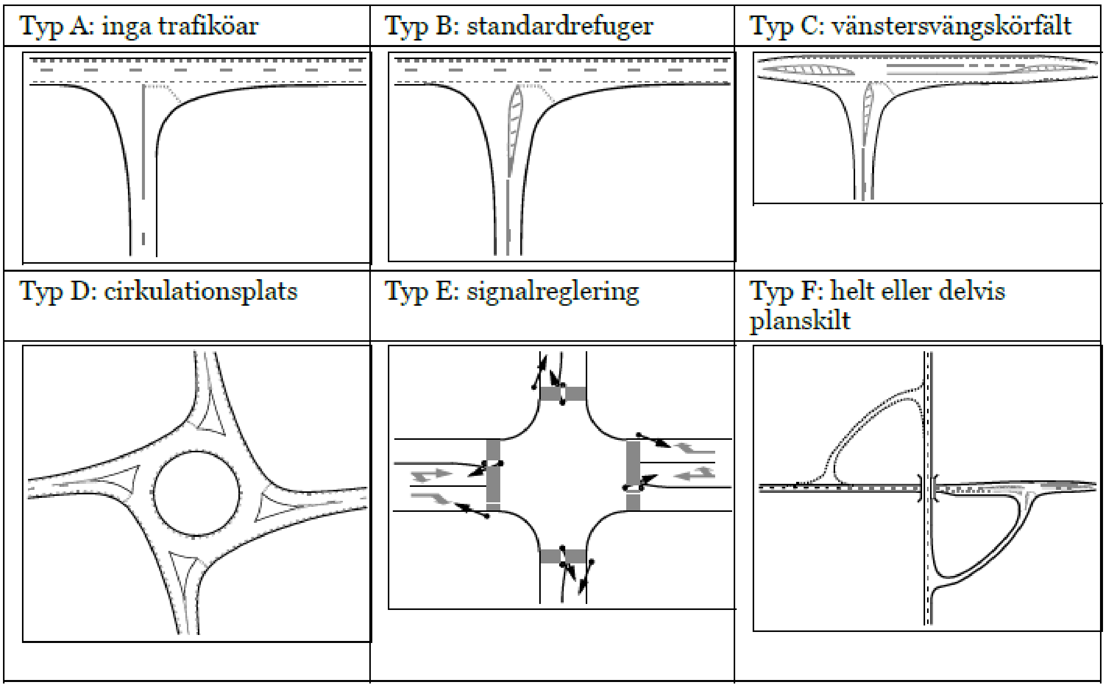

Figure 5 *Different types of intersections where "typ" is the Swedish word for type (Swedish Transport Administration, 2018d).*

Smaller intersections are divided into:

- Type A, unchannelized intersection
- Type B, channelized intersection
- Type C, with lane for left turning from primary road

Unchannelized intersections are regulated with priority of the right, right-of-way or stop signs (Swedish Transport Administration, 2004). Channelized intersections separate the traffic flows into separate lanes, this can be done by raised traffic islands or painted markings on the road (Swedish Municipalities and County Councils, 2009). Reasons for this can be many, involving minimizing the conflict points, increasing the sight, defining desired driving pattern or defining the prioritized road. The main reason is to increase the accessibility and/or safety.

The larger intersections are divided into:

- Type D, roundabout
- Type E, signalized intersection
- Type F, partially or entirely elevated intersection

In the larger intersections, actions have been taken to increase the accessibility for traffic on the secondary road, which also leads to increased safety (Swedish Transport Administration, 2004). Which intersection to choose is determined from an economical point of view with regard to technical demands, based on speed limit, yearly and hourly flows (Swedish Transport Administration, 2004). The choice also depends on accessibility, traffic safety, environment and maintenance cost.

2.4.2 Traffic safety connected to the design of intersections

Intersections are the main areas in the road system where motorized vehicle drivers are severely or fatally injured in urban areas (Swedish Municipalities and County Councils, 2013). Especially 4-legged intersections are heavily affected by accidents (Swedish Municipalities and County Councils, 2013; Swedish Transport Administration, 2004). The major affecting factors for accidents in intersections are the complexity (including number of incoming approaches) of the intersection, high speed limit and a large traffic volume. The choice of smaller or larger intersections and the proportion of incoming traffic from the secondary road are also important factors.

Roundabouts are by many considered to be among the safest type of intersection (Swedish Municipalities and County Councils, 2013). The reason they are considered to be safer is not because of a decrease in the number of accidents, but that the severity of the injuries is considerably lower. These conclusions originate from the fact that the speed of the vehicles automatically gets lower when entering the roundabout, and thereby reducing the degree of the injury if an accident occurs. Another reason for the decreased risk of severe injuries is that the angle of impact between the vehicles also decreases and the risk of a 90-degree angle between the vehicles is eliminated. In other types of intersections where 90-degree accident angle can occur, the injuries can be very severe even in low speeds. Roundabouts are advantageous where the traffic from the secondary road is over 25-30% of the total volume in the intersection (Swedish Transport Administration, 2004).

When passing an intersection the speed limit is, in general, important not to be higher than 60 km/h since the risk of being killed in an accident increases at higher speed (Swedish Municipalities and County Councils, 2013). Speed limits in intersections with no pedestrians or cyclists should not exceed 50 km/h when passing the intersection. In intersections with unprotected road users, the design of the roads and intersections shall not enable speeds over 30 km/h.

It is a challenge to design a signalized intersection to be suitable for both vehicles and pedestrians (Kronborg, 2007). The pedestrians' needs are different from the motorized vehicles and for a long time the vehicles have been prioritized. It is more common for pedestrians to cross the road when the signal is red than for cyclists and vehicle drivers.

According to Kronborg (2007) 80 % of the fatal injured pedestrians in traffic were walking against a red signal.

2.4.2.1 Conflict points

Conflict points are the theoretical points in where two (or more) vehicles, a vehicle and pedestrian or a vehicle and cyclist collide. The number of conflict points increases the likelihood of a collision and the complexity of the intersection (Pande & Wolshon, 2016). Minimizing the number of conflict points leads to safe and efficient crossings while at the same time minimizing the accident frequency. When the incoming traffic volume increases, the probability of conflict between road users also increases.

Conflict points for vehicles are traditionally based on the traffic flow entering and exiting the intersection (Pande & Wolshon, 2016). This results in, for a 4-legged intersection, a total of 32 conflict points for motorized vehicles, divided into crossing, diverging and converging points. There is a big difference in the number of conflict points when comparing to a roundabout which only has a total of eight conflict points, Figure 6, whereof only diverging and converging conflict points (Gross, Lyon, Persaud & Srinivasan, 2013). A 3-legged intersection is also better in terms of the number of conflict points, with a total of 9 conflict points, where three is crossing, three is diverging and three is converging (Pande & Wolshon, 2016).

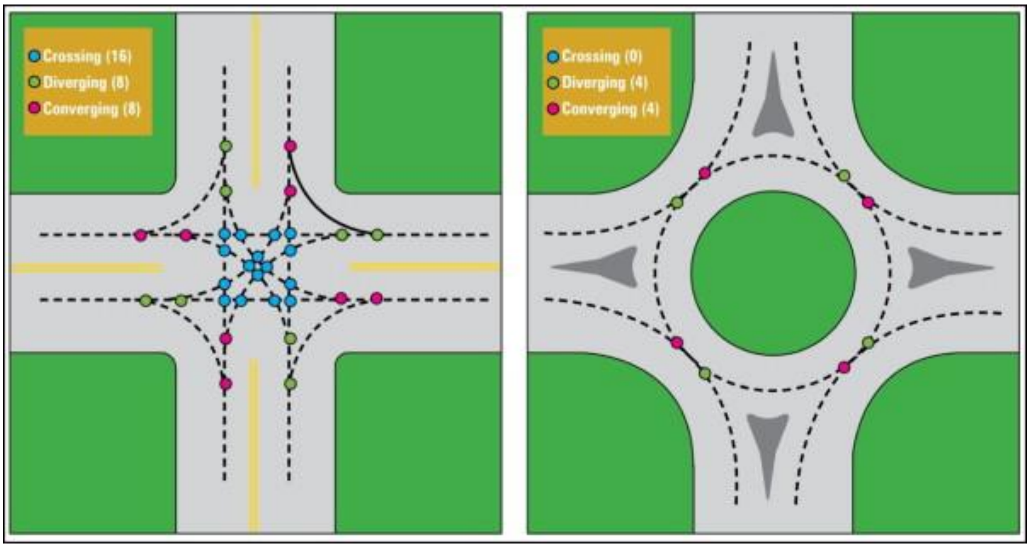

Figure 6 Conflict points in a 4-legged intersection and in a roundabout (Gross, Lyon, Persaud & Srinivasan, 2013)

2.4.2.2 Normal values for the number of accidents

Swedish standards and guidelines on how to estimate the number of accidents and injuries depending on the flow can be found in Swedish Transport Administration (2018d). The normal values can be calculated to predict the number of accidents per year, predict the injuries, degree of severity and fatality accidents. To calculate the normal values for motorized vehicles information about number of incoming approaches (3 or 4) is needed. A 4-legged intersection also requires information about the traffic volume distribution, speed limit, road environment and the design of the intersection.

Another way of measuring the safety in an intersection is to use the number of average accidents per year, which is based on the average cost of an accident (Swedish Transport Administration, 2004). This number is used when deciding which type of intersection to implement depending on traffic safety. Larger intersections should be considered when the traffic volume on the secondary road is in the same magnitude as the traffic from the primary road or when a smaller intersection has unfulfilled safety requirements.

2.4.3 Actions for safety improvements

When analysing potential actions for improvements for safety in intersections it is necessary to consider that drivers will eventually adjust their driving to the new implementation (Swedish Transport Administration, 2018d). Over time the speed may therefore increase and a new situation will emerge. The positive effects of the new implementation, in other words the number of accidents, can be challenged by more severe injuries in the accidents that may still occur. According to Pande & Wolshon (2016) it is of importance to understand the unique context of the specific intersection before considering the potential effects of the design feature.

There are several actions which can be implemented to improve an undesirable safety situation, summed up in Table 1. The table is based on Swedish Municipalities and County Councils (2013), Swedish Transport Administration (2018d) and Swedish Municipalities and County Councils (2009). By applying these actions the number of accidents with injuries will hopefully be decreased. In the table the negative percentages represent how much the number of accidents with injuries would be decreased by applying the action. The positive percentages are therefore how much the number of accidents with injuries would increase by implementing the action.

Table 1 Actions for safety improvement in intersections with the traffic safety effect.

Actions for improvement	**Traffic safety effect (number of accidents with injuries)**	**Comment**
Actions for improvement for motorized vehicles		
Sight improvement	Low	Can have an opposite effect
Raised traffic island on secondary road	0 to -10%	Improvement in 4-legged intersections only
Rumble strip	-30%	
Raised intersection	+5 to -50%	Great uncertainties in traffic safety effect
Changing from 4-legged to two 3-legged	0 to -40%	Depending on previous accident frequency
Roundabout	-20 to -50%	Depends on the current design of the intersection
Signalized intersection	0 to -30%	
Elevated intersection	Unknown	Very expensive
Actions for improvement for pedestrians and cyclists		
New zebra crossing	+26%	Creates a feeling of "false" safety
Raised traffic island on zebra crossing	-18 to -25%	
Speed secured passing	-40%	Even better effect when only considering pedestrians (-50%)
Channelization with railings	-20 to -30%	
Advanced stop line (bike box)	-40%	For cyclists -27%, and for vehicles -66%, which gives a total of -40%
Overpass or underpass	-30%	Up to -82% if only considering pedestrians

2.4.3.1 Sight improvements

Results from various studies show both positive and negative effects of improving the sight in intersections (Swedish Municipalities and County Councils, 2009). Some results show tendencies of the risk of accident increasing with an increased sight distance. This can be explained by drivers' tendency to increase the speed if the sight is good. At the same time the sight in intersections must be good enough for the driver to be able to identify obstacles and unpredicted events in time to make a decision whether it is secure to pass the intersection or not. The number of accidents per incoming vehicle is higher when the sight is worse. But the effects, in other words the severity, of the accidents are greater when the sight is good, probably due to the higher speeds. It is hard to make general recommendations for sight improvement actions because of the uncertain effects of it.

2.4.3.2 Channelization with elevated traffic island

Channelization of the secondary road with raised traffic island helps to strengthen the visibility of the intersection and thereby making it safer (Swedish Transport Administration, 2018d). A raised traffic island in a zebra crossing also makes it easier for pedestrians to cross because of the natural stop between the lanes. If the raised traffic island is located in a zebra crossing the number of accidents with injuries can decrease with up to 25% for pedestrians (Swedish Municipalities and County Councils, 2013).

2.4.3.3 Rumble strips

Rumble strips are small elevations raised transversal to the direction of the road, Figure 7. The strips create noise and vibrations in the vehicle, so the driver becomes observant of the new traffic situation (Swedish Municipalities and County Councils, 2009). The desired effect is for the driver to slow down and thereby making it safer. The strips are grouped in sets of 3-6 and by decreasing the distance between the strips and the sets, a feeling of increased speed is achieved. The more strips per set and the more sets, the greater the effect becomes. Even though if the speed is not decreased the method has had a reduction of traffic accidents, probably because of the increased attention. This method can also be used for cyclists, but does not decrease the speed significantly, nevertheless it is good for greater attention.

Figure 7 Example of design of rumble strips (Swedish Municipalities and County Councils, 2009).

2.4.3.4 Raised intersection

In a raised intersection the approaching roads are raised to be on the same level as the pedestrian paths around them. This is done to make the drivers slow down and to give attention to the approaching conflict area (Swedish Municipalities and County Councils, 2009). The achieved traffic safety effect is hard to estimate and many intersections which have been raised already had low speeds, which makes no bigger impact for the traffic safety. Results from studies show a varied effect, where one study shows an increase of accidents with injured persons by 5% and another study shows a decrease of 50% of accidents with injured persons. This type of action is good to use in areas were many unprotected road users are crossing and it is most suitable in the urban space.

2.4.3.5 Offset intersection

Intersections with four legs have a very high accident and injury frequency. To decrease the accidents an offset intersection with two 3-legged intersections can be an option (Swedish Transport Administration, 2018d), Figure 4. This solution is best for medium sized flows and the main idea of this method is to reduce the number of conflict points. Since 3-legged intersections only have 9 conflict points compared to 4-legged which have 32, the number of conflict points are successfully decreased with almost 50%

(Swedish Municipalities and County Councils, 2009). The distance between the intersections must be at least 50 meters which means that much space is needed.

2.4.3.6 Roundabouts

Roundabouts are increasing in popularity in many countries because of the high safety it offers to the drivers (Swedish Transport Administration, 2004). Roundabouts also reduces the accidents for pedestrians and cyclists, however the number of bicycle accidents are not reduced as much as for the drivers and pedestrians. The safety effect of roundabouts depends greatly on the number of lanes and the radius of the roundabout (Swedish Municipalities and County Councils, 2009). The design and the specific location for the intersection have a huge impact on the safety effect and since different types of roundabouts exists in different traffic environments it is hard to estimate a general factor for the safety effect.

2.4.3.7 Signalized intersection

Signalized intersections can have various aims, for example to increase safety, improve capacity, give priority for certain flows or to prioritize public transport (Swedish Municipalities and County Councils, 2009). In these intersections the speed limit must be 70 km/h or below. The alternative to a signalized intersection is often a roundabout. Roundabouts are advantageous in terms of safety, however if the location and the surrounding environment are limited it often results in a signalized intersection. A big disadvantage with signals is that mistakes and bad decisions made by the road users (driving or walking against a red light) can have very serious consequences (Swedish Transport Administration, 2004). This type of intersection reduces the crossing and left-turning accidents, but the rear-end accidents increases. Generally speaking, signalized intersections have approximately half as good security as of roundabouts.

2.4.3.8 Elevated intersection

An elevated intersection is the most advanced and expensive of the types of intersections given by Swedish Transport Administration (2004). Elevated intersections are intersections where the legs are separated from each other, which eliminates the conflict points for crossing vehicles, see type F in Figure 5. The biggest safety impact is when constructed in a 4-legged intersection, but the safety effect can be seen even in roundabouts, which usually is considered to be the safest type of intersection.

2.4.3.9 New zebra crossing in intersection

By implementing a new zebra crossing for unprotected road users a feeling of false safety can be created (Swedish Municipalities and County Councils, 2009). Studies have shown that the safety actually is worse in zebra crossings than in other places, reason being that pedestrians get a feeling of safety even though the marking is not actually making it safer. This should therefore be seen as a measure for increased mobility, and not a safety measure, for the unprotected road users. Therefore, it is recommended to use zebra crossings together with other actions, to achieve the desired safety effect.

2.4.3.10 Speed secure passing

A speed secured passing is designed to make sure that the motorized vehicles do not exceed a chosen speed limit at a conflict point (Swedish Municipalities and County Councils, 2009). As previously mentioned the speed should not exceed 30 km/h in an intersection where unprotected road users are present. Several methods can be used to speed secure an intersection, including:

- Pedestrian and cyclist overpass or underpass
- Speed bump before intersection
- Dynamic speed bumps, which rises for drivers who are driving too fast
- Camera surveillance

2.4.3.11 Channelization with railings

Another action to improve the safety for unprotected road users is to use railings to divert and channelize bicycle and pedestrian flows to appropriate passing locations (Swedish Municipalities and County Councils, 2009). Cyclists and pedestrians often choses the easiest and quickest way to cross over, which could lead to risky situations. By this method the number of accidents involving unprotected road users is reduced, also a reduction involving only vehicles can be found. When using railings with no possibility to see through, the accidents decreases with an average of 24% for pedestrians and 8% for private vehicles. If the railings are designed to be able to see through the safety effect is on average -33% for pedestrians and -50% for drivers. The statistics for cyclists are unknown. This method can be used together with speed secured passing for greater safety effects. Some disadvantages are that the urban space is signalizing priority for vehicle traffic and makes it harder for pedestrians to choose the quickest path. This can be seen as negative from a sustainability approach where walking and cycling should be prioritized.

2.4.3.12 Advanced stop line

An advanced stop line or so-called bike box is a design of signalized intersection where the cyclists stop line is placed closer to the intersection than the vehicles, creating a box where cyclists are placed in front of the vehicles, Figure 8 (Swedish Transport Administration, 2004). The advanced stop line is advantageous especially in intersections with long red signal time or many cyclists going straight forward. It also reduces primarily the number of accidents between cyclists going straight through and vehicles turning right. The safety effect for this is not based on statistics from accidents but are estimated from studies of conflict points.

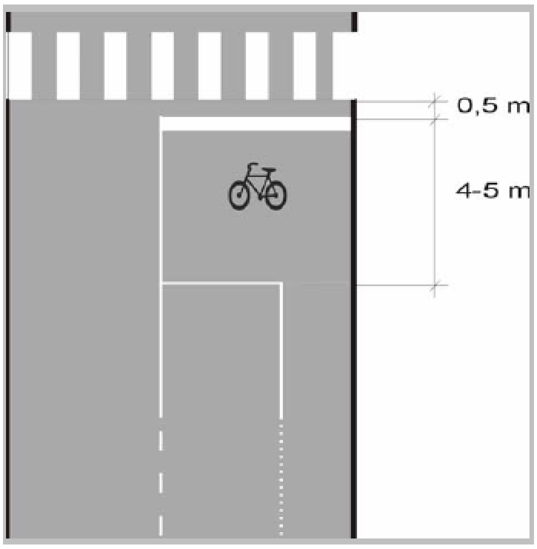

Figure 8 Design of a traditional bike box from Swedish Transport Administration (2004).

Alternatives for the traditional bike box are to only have an advanced stop line for cyclists in the bicycle lane, making them more visible to drivers and/or to have an earlier green signal for the bicycle traffic (Swedish Municipalities and County Councils, 2009). This method is also advantageous from a sustainability perspective since it invites and prioritizes sustainable transportation modes.

2.4.3.13 Overpass or underpass for pedestrians and cyclists

By separating the motorized traffic from pedestrian and bicycle traffic with an overpass or underpass (tunnel or bridge) both better safety and better mobility will be achieved (Swedish Municipalities and County Councils, 2009). This action is appropriate where the speed limit is 50 km/h or higher or where the vehicle traffic flow is very high. It can be very hard to build in already built-up or dense areas, therefore overpasses or underpasses are mainly used in suburban or periphery parts of a city. For the overpass or underpass, the safety effect is dependent on if the passage is used. If people still cross on street level the risk of accidents gets higher due to higher speed and decreased attention by the drivers. In several cases underpasses, in other words tunnels, can cause a feeling of insecurity for the users mostly due to bad lightning, vegetation as well as narrow and uninviting tunnels. A good designed tunnel should be possible to see through from long distances before the actual underpass.

3 Description of Strada

This chapter gives a short description of Strada and includes an introduction, information about the confidentiality, explanation of the degree of the injuries and the types of accidents.

3.1 Introduction to Strada

Strada is a national information system about injuries and accidents in the transport sector (Ministry of Enterprise and Innovation, 2016). It is the police and emergency hospitals who report the information about the accidents and the Swedish Transport Agency has the responsibility for the information. The database also has a map tool based on maps from the Swedish “Lantmäteriet”, data from traffic registry from the Swedish Transport Agency and data from NVDB. By using Strada it is possible to find information about how many accidents that have occurred in a specific area, which type of accidents, how serious the accidents were, age and gender of the injured persons, which type of vehicles that were involved etc.

The police report the accidents that have occurred in traffic when at least one vehicle has been involved and there are persons that are injured or dead (Ministry of Enterprise and Innovation, 2016). It is mandatory for the police to report the accident when they have been at the location of the accident. The emergency hospitals on the other hand report when a person has been injured in traffic environment and visits the hospital, with approval from the patient. The information from the hospital gives a good picture of how severe the injuries are by diagnosing the patient. For those who get treatment for an accident that has occurred in a traffic environment it is offered to fill in a form which can be registered in Strada. For those who visited the hospital it is therefore optional if they want the injury to be registered or not with the purpose to reach a safer traffic environment.

By using two sources as a base for information the knowledge increases about injured persons in traffic (Ministry of Enterprise and Innovation, 2016). The information from the hospital gives a good picture of how severe the injuries are by diagnosing the patient. The hospitals also collect information about the unprotected road users, pedestrians and cyclists, which the police not always get information about.

3.2 Confidentiality

The information from Strada is protected by the Personal Data Act and the Public Access and Secrecy Act to ensure that the information about individuals is confidential (Ministry of Enterprise and Innovation, 2016). Because of that the database is built up so that the information from the police and hospitals are matched and then unidentified. This means that information about name, personal ID and registration numbers are not available for the users of Strada withdrawal web.

The information found in Strada can however be linked to other information to identify individuals (Ministry of Enterprise and Innovation, 2016). Therefore, all Strada users needs to agree to use the information in a correct way and not spread the information to unauthorized.

3.3 Degree of injuries

How severe an injury is, is evaluated by the hospitals according to an international injury classification, the Abbreviated Injury Scale (AIS) (Swedish Road Administration, 2006). AIS is a measurement on how life threatening the injury is on a scale 1-6 where one is a mild injury and six a fatal injury. The Injury Severity Score (ISS) is on the other hand an index of surviving from multiple injuries and is calculated from the AIS for those three body regions that have the most severe injuries. The ISS is calculated by the sum of all injuries that a person sustains. ISS can be between the values 1 to 75.

In Strada the injuries are ranked in ISS as following:

0	Not injured
1-3	Mild injury
4-8	Moderate injury
>9	Severe injury

The fatal injuries are not ranked since there is no value for this type of injury. Persons have different prerequisites to tolerate the strain on the body caused from an injury, therefore it is not possible to put a number on fatal injuries. As fatally injured in a traffic accident is when a person has died within 30 days due to the accident (Swedish Transport Administration, 2018c).

3.4 Types of accidents

The different accidents that occur in the road system are categorized and presented according to Strada as described below.

Bicycle/Moped with vehicle	Collision between bicycle or moped and vehicle.
Bicycle with bicycle	Collision between bicycles.
Crossing vehicle	Collision between motorized vehicles with different directions, crossing each other's paths.
Meeting vehicle	Collision between motorized vehicles with meeting direction.
Parked vehicle	Collision between motorized vehicles were at least one of them are parked or standing still.
Pedestrian with bicycle	Collision between pedestrian and bicycle.
Pedestrian with vehicle	Collision between pedestrian and vehicle.
Rear-end vehicle	Collision between motorized vehicles with the same direction where the rear vehicle has reached the one in front.

Reversing/U-turn	Collision between a motorized vehicle that are reversing or in a U-turn with vehicle.
Single accident with bicycle	Accident where only one bicycle is involved.
Single accident with moped	Accident where only one moped is involved.
Single accident with vehicle	Accident where only one vehicle is involved.
Tram	Collision between road user and tram.
Turning vehicle	Collision in an intersection between motorized vehicles at the same road, with the same or opposite direction, where at least one of the vehicles are turning.
Other	Other types of collisions, for example between motorized vehicles and animals (not wild), between tractor and vehicle.

4 Method

This chapter describes the reports process to conduct the study done in this report. The studied intersections and the used data are described together with the approach of the study. In the study 20 intersections were investigated considering flow and design in order to find information about the traffic safety, correlation of flow and safety and how to improve the safety.

4.1 Description of the investigated intersections

The studied area in this report is Gothenburg where 20 intersections have been investigated and evaluated. All of the intersections are 4-legged, located in the urban area of Gothenburg and some of them have a tramway rail and/or traffic signals, Table 2. A map over the intersections locations in Gothenburg can be seen in Appendix I.

Table 2 The investigated intersections showing if there are any tramway or traffic signals in the intersection.

No.	Intersection	Tramway	Signalized
1	Parkgatan/Södra vägen		x
2	Kungsportsavenyen/Engelbrektsgatan	x	x
3	Fridkullagatan/Liljeforsgatan		
4	Skånegatan/Levgrensvägen/Bohusgatan	x	x
5	Såggatan/Amiralitetsgatan		
6	Andra Långgatan/Värmlandsgatan		
7	Södra vägen/Engelbrektsgatan	x	x
8	Engelbrektsgatan/Sten Sturegatan		x
9	Mölndalsvägen /Sankt Sigfridsgatan/Fredrikdalsgatan	x	x
10	Lorensbergsgatan/Kristinelundsgatan		
11	Olivedalsgatan/Alfhemsgatan		
12	Linnégatan/Nordenskiöldsgatan	x	x
13	Kustgatan/Karl Johansgatan	x	x
14	Nya Allén/Kungsportsavenyen	x	x
15	Parkgatan/Sten Sturegatan		x
16	Första Långgatan/Nordhemsgatan	x	x
17	Härlandavägen/Stockholmsgatan/Kålltorpsgatan	x	x
18	Delsjövägen/Töpelsgatan/Birkagatan		
19	Torgny Segerstedtsgatan/Fågelvägen	x	x
20	Munkebäcksgatan/Colliandersgatan/Torpavallsgatan		x

An observation from the studied intersections was that in the intersections with tramway the tramway rail often was located between the lanes of the road with the tram stops close to the traffic signals and in connection to the intersection. Another observation was that most of the roads with traffic signals were regulated by time where each leg of the intersection was allowed to drive, or pedestrians to pass the road, at different times in order to prevent a collision.

The 20 intersections that were investigated were chosen since they all had the speed limit 50 km/h, were 4-legged and had various design and/or different flows. The accident statistics does not consider if the investigated intersections had been rebuilt for the last ten years. However, for the improvement proposals it was considered if the intersections recently had been rebuilt since actions already had been done.

An important factor when choosing the intersections was that data could be found about the traffic flow for all legs in each intersection. Another factor was to avoid intersections located on the same road.

4.2 Data description

The data needed for this study was accident injury data, traffic volume in AADT and speed limit. For the comparison of intersections AADT was collected from the City of Gothenburg (n.d.) and speed limits from NVDB (Swedish Transport Administration, 2016). The accident statistics was collected from Strada which has information about the accidents, such as type of accident, severity and location. The accident statistics was represented by the number of injured persons during a time period of 10 years, from January 1, 2008, to December 31, 2017. The accidents with injuries were selectively chosen in order to find the accidents with injuries that occurred in the area of the intersections. Accidents with pedestrians in a single accident were not considered. The accidents with injuries where the injury was unknown or uncertain were also not considered.

When collecting the AADT it was important that each leg of the intersection had data for incoming and outcoming flow. Also, that the measurement of the AADT was conducted for a specific stretch with not too many roads connecting before the intersection.

4.3 Calculation of AADT for 2018

In order to examine the relationship between the flow and traffic accidents the AADT needed to be specified. Since there were no measurements of the AADT done in the middle of each intersection, the flow needed to be calculated to find the incoming flow for each leg in the intersection. Only the incoming flow needed to be taken in consideration on the grounds that the measured vehicles of the intersections both were inbound and outbound. That means that the vehicles were measured two times since measurements were taken for each leg. Therefore, only the incoming flow needs to be taken into account since the vehicles not should be considered more than one time.

According to the Swedish Transport Administration (2018e) estimations, the AADT is expected to increase with a factor of 1,29 from year 2014 until year 2040 in metropolitan Gothenburg. Since the used values from the City of Gothenburg (n.d.) were measured at different occasions enumerations must be done in order to get the AADT for the same year for all intersections according to equation 1. The calculated values of AADT for 2018 can be found in Appendix II.

$$AADT_{2018} = AADT_{measured} * (1{,}29^{(\frac{1}{2040-x})})^{2018-x} \qquad (1)$$

where

$AADT_{2018}$	is the calculated AADT for each leg for 2018
$AADT_{measured}$	is the measured AADT taken from the City of Gothenburg
x	is the year when the $AADT_{measured}$ was measured

To calculate the AADT for the whole intersection the flow from the four legs were added together to get the total AADT in the intersection. However, it also had to be divided by two to only get the incoming flow from the four legs in the intersection. It is assumed that the incoming flow for 24 hours is the same as the outcoming flow for the same amount of time for each of the investigated intersections. By assuming that, the flow for 24 hours can be divided into two equal parts.

4.4 Correlation regarding flow and safety

To find out if there is a correlation between flow and safety the number of injuries were plotted against the calculated incoming AADT for each one of the 20 selected intersections using MS Excel. A simple linear regression line was used, meaning that the correlation is linear and only depending on two independent variables, in other words the flow and the injuries. By using a trend line the R^2 value was obtained through MS Excel. The R^2 is a value of the goodness of fit of the trend line. The R^2 value is given between 0 and 1, where 1 is a perfect fit between the trend line and the data.

4.5 Improvement proposals

In order to present improvement proposals, the most common accidents that occur in Gothenburg were found. The most frequently occurred accidents were considered and studied to find out in which intersection it had caused the most injured persons. The intersections were then examined in order to find improvement proposals. The improvement proposals were considered if they were applicable on the studied intersection in order to prevent the accident to occur. The improvement proposals that were suggested for the studied intersections are based on the literature review.

The intersections were illustrated with inbound and outbound lanes, conflict points and if there were any tramway rail located in the intersection. The accidents that had occurred for each intersection were studied in Strada in order to find information on where, when and why the accidents had occurred. Improvement proposals were finally designed on the basis of understanding how and why the accidents occurred.

4.5.1 Field study

A field study was conducted for the intersections, in which improvements were presented for. This was done in order to get a better understanding of the design and traffic situation in each intersection. Observations were done during March 14, 18 and April 1, 2019 at 10 AM. The weather during the observations was clear and the conditions were assumed to represent a normal traffic situation.

5 Correlation between flow and safety

In this chapter the correlation between flow and safety has been investigated by an examination of the 20 4-legged intersections. The number of accidents in respectively intersection are presented in Table 3, together with the severity of the injuries and the calculated incoming AADT in each intersection.

Table 3 The injuries and AADT for each area that was investigated.

		Number of injured persons					AADT in
No.	**Intersection**	**Dead**	**Severe**	**Moderate**	**Mild**	**Total**	**intersection**
1	Parkgatan/Södra vägen	0	1	0	22	23	14 402
2	Kungsportsavenyen/Engelbrektsgatan	0	0	1	14	15	9 551
3	Fridkullagatan/Liljeforsgatan	0	0	0	4	4	8 788
4	Skånegatan/Levgrensvägen/Bohusgatan	0	3	1	17	21	18 641
5	Såggatan/Amiralitetsgatan	0	0	1	1	2	4 322
6	Andra Långgatan/Värmlandsgatan	0	0	2	0	2	8 455
7	Södra vägen/Engelbrektsgatan	0	0	4	22	26	19 460
8	Engelbrektsgatan/Sten Sturegatan	0	1	0	7	8	14 080
9	Mölndalsvägen/Sankt Sigfridsgatan/Fredrikdalsgatan	1	1	0	29	31	28 527
10	Lorensbergsgatan/Kristinelundsgatan	0	0	0	8	8	3 448
11	Olivedalsgatan/Alfhemsgatan	0	0	0	0	0	1 392
12	Linnégatan/Nordenskiöldsgatan	0	0	0	7	7	9 195
13	Kustgatan/Karl Johansgatan	0	0	1	3	4	8 858
14	Nya Allén/Kungsportsavenyen	0	0	8	25	33	14 214
15	Parkgatan/Sten Sturegatan	0	0	2	15	17	14 096
16	Första Långgatan/Nordhemsgatan	0	0	1	7	8	8 422
17	Härlandavägen/Stockholmsgatan/Kålltorpsgatan	0	0	0	15	15	7 814
18	Delsjövägen/Töpelsgatan/Birkagatan	0	1	1	8	10	11 262
19	Torgny Segerstedtsgatan/Fågelvägen	0	0	2	17	19	16 375
20	Munkebäcksgatan/Colliandersgatan/Torpavallsgatan	0	2	2	7	11	26 999

The number of injuries in each intersection was plotted to the AADT for the corresponding intersections to establish the correlation between flow and accidents with injuries, Figure 9.

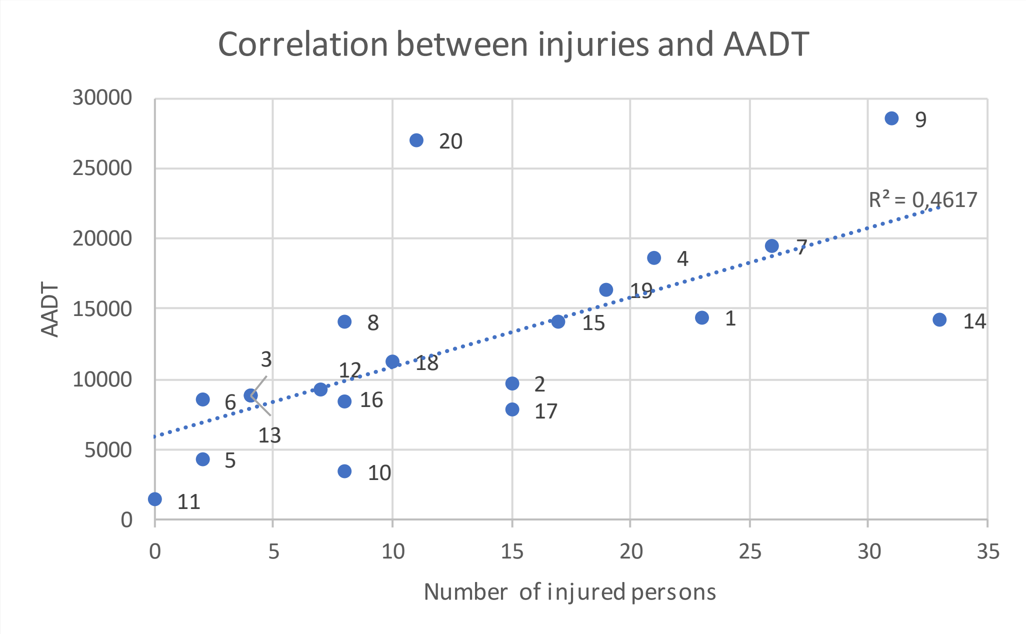

Figure 9 *Correlation between accidents with injuries and AADT. The numbers in the figure represent the intersection number from Table 3. Author's own copyright.*

From the literature study it was found that a higher AADT would give a higher accident rate, which also can be seen as likely from this study. From Figure 9 it is noted that the R^2 value is 0,4617, which can be interpreted as a trend in the correlation as 68%. From the figure it can also be seen that there are three values (9, 14 and 20) that does not follow the trend line, so-called outliers. By removing the outliers the correlation changes and the R^2 value is instead 0,6717 which can be interpreted as a stronger trend in the correlation as 82%, Figure 10. The outliers are removed to investigate how much difference the outliers have on the R^2 value.

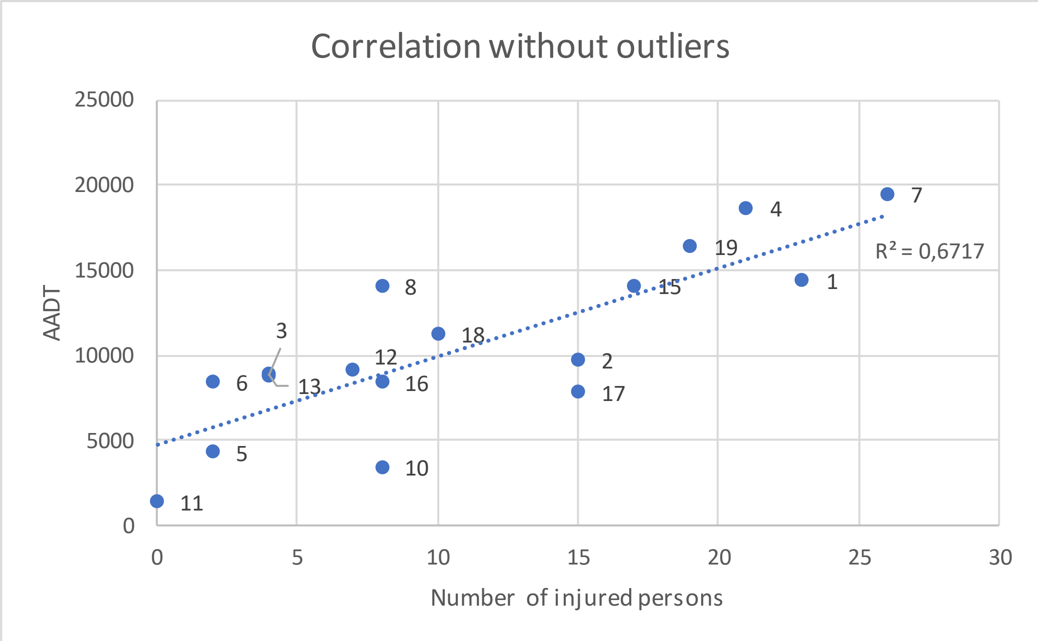

Figure 10 *Correlation between accidents with injuries and AADT after removing the outliers. The numbers in the figure represent the intersection number from Table 3. Author's own copyright.*

5.1 Correlation analysis

From the correlation graph (Figure 9) some connections can be distinguished for further analysis. Four intersections with similar AADT but with a variation of number of injuries were compared. After this, three intersections with different AADT and with the same number of injuries are compared. The accidents that occurred in the intersections are analysed to see if any conclusion about the differences can be found.

5.1.1 Comparison of intersections with similar AADT

Four of the 20 investigated intersections have around 14 000 AADT but at the same time a variety of number of accidents, Figure 9. These intersections, number 1, 8, 14 and 15, are compared to find causes which can affect traffic safety other than the AADT. Information about the intersections can be found in Table 4 ranked after total accidents with injuries. The four intersections are located in the same area in central Gothenburg relatively close to each other, Figure 11.

Table 4 Information about the four intersections, ranked after total accidents with injuries.

Intersection	AADT	Total accidents with injuries	Tramway	Signalized	Total incoming lanes
14	14 214	33	Yes	Yes	4
1	14 402	23	No	Yes	5
15	14 096	17	No	Yes	7
8	14 080	8	No	Yes	9

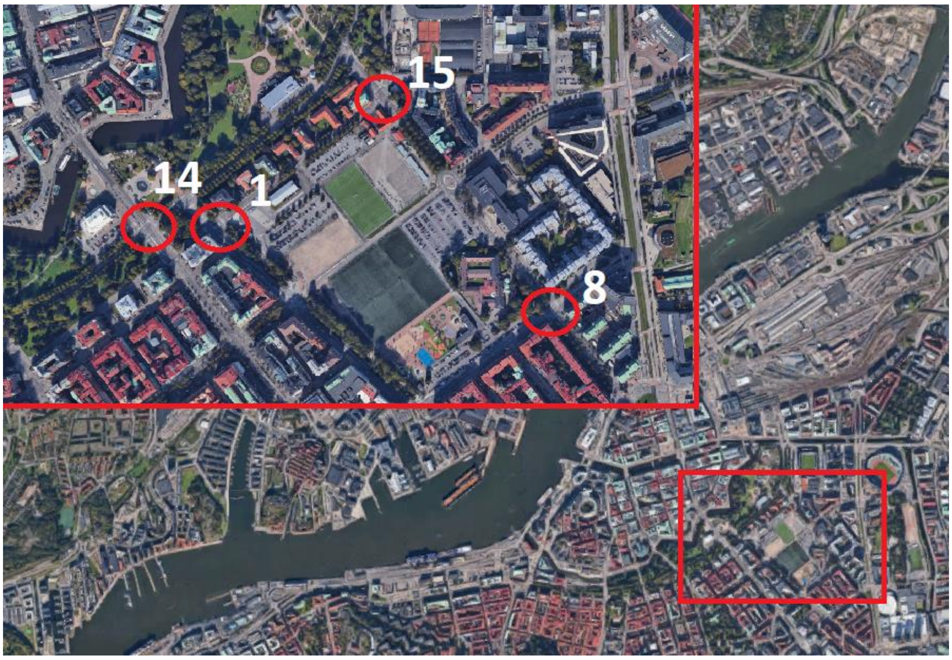

Figure 11 Location of examined intersections in Gothenburg. Figure adjusted from Google maps (2019).

Intersection 14 is the intersection with the most injuries out of all the 20 investigated intersections. The intersection is located very central with many buses and trams crossing, together with a broad flow of pedestrians and cyclists. The traffic is one-way bound from east to west and only public transport are outbound in the south leg. Intersection 1 and 15 also contains one-way streets with direction from west to east and inbound traffic in intersection 1 is limited to buses. Intersection 8, with the least injuries in this context, has no public transport and all legs are roads with traffic in both directions. Based on each above description it could be argued that intersection 14 has a more complicated traffic situation, followed by 1 and 15. Intersection 8 would then have the most comprehensible traffic situation, with no buses, trams, no one-way street and many lanes in the incoming legs. An overview of the four intersections can be seen in Figure 12.

Figure 12 Intersections with similar AADT. From the left: Intersection 14, 1, 15 and 8 (Google maps, 2019).

A comparison of the type of accidents in the intersections shows that for intersection 14 the number of injured unprotected road users is more than two thirds of the total number of injuries, see Table 5. When many transport modes are using the same space, more conflict points emerge and since many unprotected road users are using the space in intersection 14, this can be the reason for the many injuries that occur in this specific intersection. Intersection 1 on the other hand, has the most accidents affecting road users in private vehicles, most often caused by other vehicles driving against red. Since all four of the compared intersections are signalized it is unknown why this specific intersection has more accidents due to unlawful driving against red.

Table 5 Number of injuries after type of road user.

Intersection	Unprotected road users	Road users in vehicles	Total
1	5	18	23
8	4	4	8
14	23	10	33
15	7	10	17

To conclude this comparison of intersections with similar AADT it can be noted that the four intersections have a similar design with all of them having traffic signals and three of them have one-way streets in at least one direction. Since they have similar AADT the difference in accident statistics has other explanations. A possible explanation is the complexity of the intersection and how it is perceived as a road user. Also, intersections with many different transport modes leads to more possible conflicts between the modes and a more complex situation.

5.1.2 Comparison of intersections with the same number of injuries

By comparing the three intersections that have the same amount of accidents with injuries but various AADT this study attempts to find similarities and differences related to the number of injured persons. The intersections that are compared are 8, 10 and 16, Table 6.

Table 6 Information about the intersections 8, 10 and 16.

Intersection	AADT	Total accidents with injuries	Tramway	Signalized	Total incoming lanes
8	14 080	8	No	Yes	9
10	3 448	8	No	No	3
16	8 422	8	Yes	Yes	6

It is notable when investigating the intersections that they all are different in the design. Intersection 10 is a small intersection located in direct proximity to buildings and has three legs that are one way. Both intersection 8 and 16 are larger signalized intersections. Intersection 16 has a tramway passing the intersection straight through from east to west and is the only intersection where public transport passes the intersection. All of the intersections have buildings that more or less surrounds the road with varying distances. The number of lanes is also different and both intersection 8 and 16 have more lanes than intersection 10 which makes the area larger and gives a better sight for the drivers. Since the tramway goes through intersection 16 a larger area opens up which gives a good sight for the road users. An overview of the intersections can be seen in Figure 13.

Figure 13 The intersections that have the same amount of accidents with injuries. From the left: intersection 8, 10 and 16 (Google maps, 2019).

When considering the number of injuries, it is notable that intersection 10 only has mild injuries while intersection 8 has one severe injury and intersection 16 has one moderate injury. In intersection 8 the severe injury was of the type of accident “pedestrians with vehicle” and the accidents that occurred, occurred at different times of the day. In intersection 16 the moderate injury was of the type of accident “tram” and the majority of the occurred injuries were also due to tram. For intersection 10 on the other hand it is seen that all injuries, except for one, occurred during night time with either the type of accident “crossing vehicle” or “pedestrian with vehicle”. Since intersection 10 is a smaller intersection it is possible that these types of injuries occur due to bad sight or bad lightning during the night. It is also possible that due to the infrastructure the drivers have a lower speed in the intersection resulting in milder injuries.

From this comparison, it is notable that the human factor and the coincidence affect the traffic safety. Also, sight is a possible reason to why the intersections have the same amount of injuries but differs in AADT. This also highlights the fact that the design of an intersection is important from a traffic safety point of view.

6 Analysis of accidents in intersections in Gothenburg

In this chapter the results from the investigation of the 20 4-legged intersections in Gothenburg are presented. The 20 intersections that have been investigated are compared and evaluated in order to find which intersections that are most affected by accidents.

6.1 Total number of injuries in the investigated intersections

The injuries that are presented for each intersection are taken from Strada, which has been thoroughly investigated. Figure 14 shows how many accidents with injuries that have occurred for each intersection during a 10-year period. The figure is based on the information in Table 3 in Chapter 5.

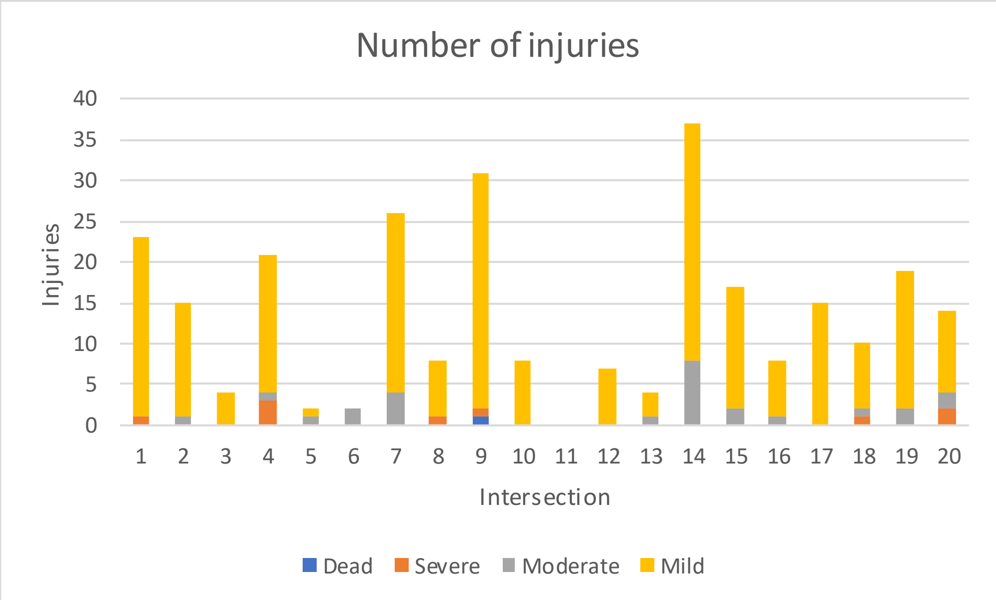

Figure 14 Number of injuries for each intersection. The figure is based on information from Strada. Author's own copyright.

From Figure 14 it can be seen that most of the injuries are mild for the majority of the investigated intersections. According to Vision Zero it is the fatal and severe injuries that needs to be reduced in order to reach the goal. Therefore, it can be argued that the fatal, severe and moderate injuries are more important to consider when indicating which intersections that are less safe and possibly needs to be improved, Figure 15. Moderate injuries are also taken into account since it is preferable to reduce those injuries as well.

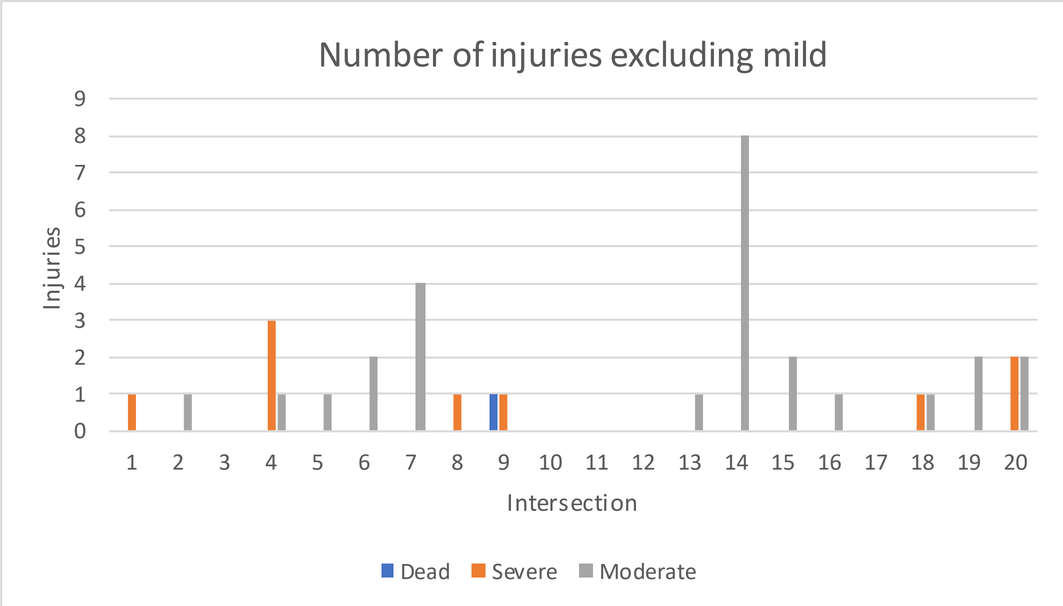

Figure 15 *Number of injured persons for each intersection excluding the mild injuries. The figure is based on information from Strada. Author's own copyright.*

When excluding the mild injuries, it can be seen that the figures change and that some intersections that previously seemed to be very unsafe, due to the many mild accidents, might not be more unsafe than others in terms of the severity of the injuries.

6.1.1 Injuries per AADT

Figure 16 shows the number of injured persons per AADT, this gives an illustration of how many persons that are injured in relationship to how high the flow is. In this figure intersection 10 and 14 have a high number of injured persons per vehicle due to the many accidents with injuries that occur in relation to the flow. Intersection 9 on the other hand has the second most accidents over all, however it is not outstanding in this figure since it has a high flow.

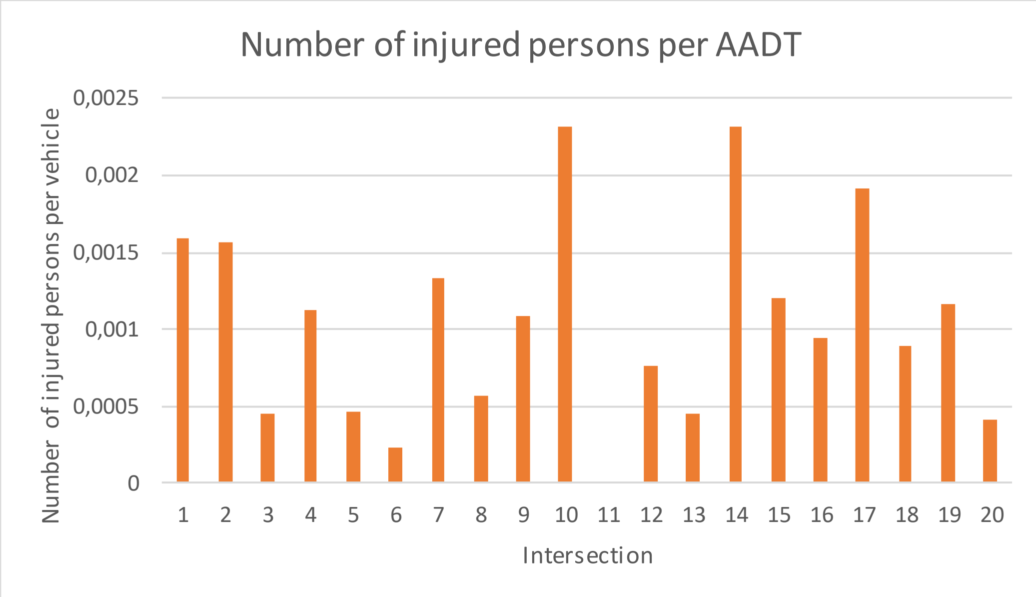

Figure 16 Number of injured persons per AADT in the investigated intersections. Author's own copyright.

6.2 Common types of accidents

Which types of accidents that have occurred in the investigated intersections were found in Strada. From this information tendencies of which type of accidents is common in intersections in Gothenburg can be distinguished. It can be seen that rear-end accidents are the accidents where the most persons got injured, Figure 17. Also, pedestrians in collision with vehicle and crossing accidents are accidents with many injuries. The figures in this Section are based on information from Appendix III.

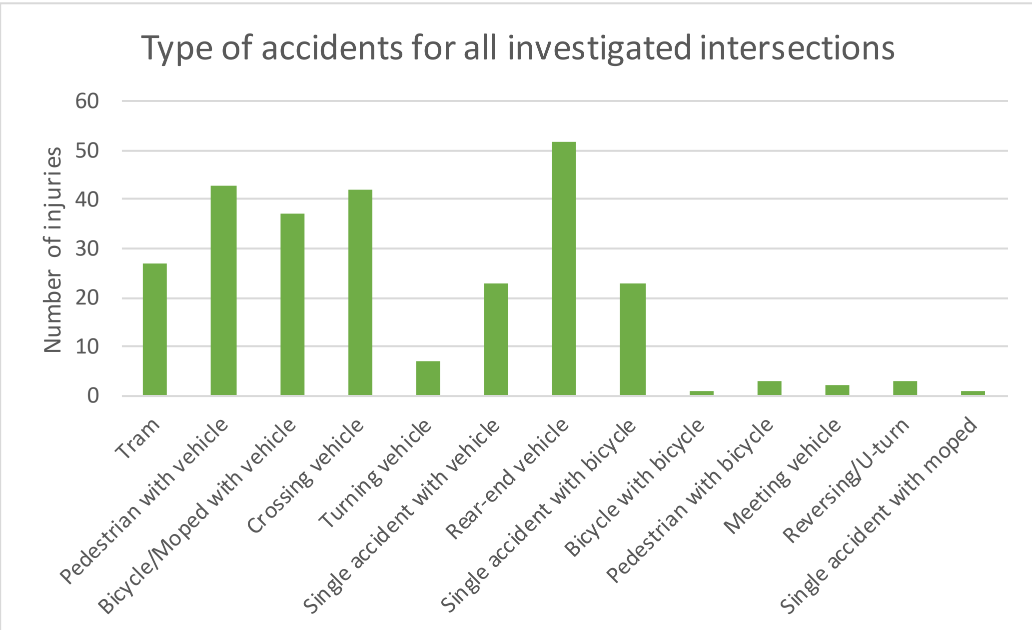

Figure 17 Number of injuries for all investigated intersections in Gothenburg. The figure is based on information from Strada. Author's own copyright.

Figure 17 shows how many injuries that occurred when including all types of injuries. Since there are many mild injuries in these intersections it is important to also consider which accidents that contributes to fatal, severe and moderate injuries, Figure 18. It can thereby be seen that the accidents where most persons got more severely injured are in collision between the unprotected road users and vehicles. Also, single accidents with bicycle and accidents connected to the tram as well as single vehicle accidents are accidents where many serious injuries occur.

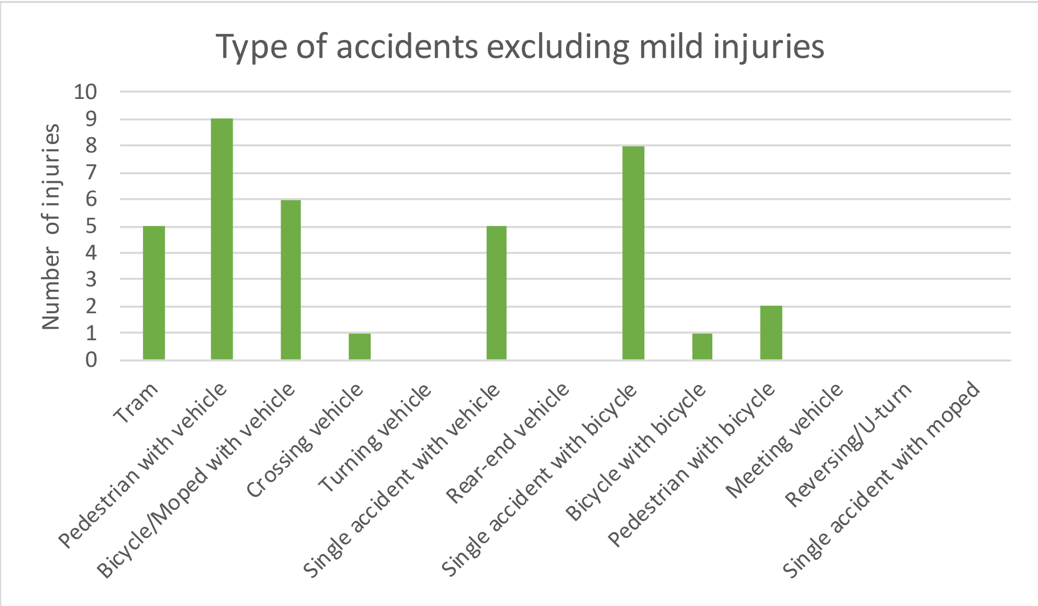

Figure 18 Fatal, severe and moderate injuries for all investigated intersections in Gothenburg. The figure is based on information from Strada. Author's own copyright.

The differences between the types of accidents for all severity levels and the types of accidents when excluding mild injuries are analysed. It can be observed that the leading type of accident for accidents overall is the rear-end accidents which have no injuries when excluding mild injuries. The same pattern is seen in the type of accident "crossing vehicle" where only one of the 42 accidents was of higher severity level than mild. The leading type of accident without mild injuries is pedestrian with vehicle where the share of more severe accidents is 9 out of 43, which is approximately one fifth of the total number of accidents. The same can be noted for accidents involving tram, bicycle or moped in conflict with vehicle as well as single vehicle accidents. Some types of accidents have a large share of high severity level accidents, such as bicycle with bicycle and pedestrian with bicycle. For example, the only accident involving bicycle with bicycle is a moderate accident and for the type "pedestrian with bicycle" two of three were of higher severity level than mild. However, because of the very low number of these accidents in total it can be considered as uncertain numbers. In general, it can be noticed that it is the unprotected road users that are in risk to get more serious injuries considering all types of accidents.

6.2.1 Accidents in intersections with and without a tramway rail

Since this study involves traffic safety for all transport modes in the intersections it is important to take the trams into account in order to find if there are a connection between accident statistics and the tramway rail. Half of the investigated intersections have a tramway rail located in connection to the intersection, Table 2 in Section 4.1. Figure 19 shows the types of accidents with the investigated intersections divided into intersections with tramway and intersections without tramway. As can be seen in the figure accidents involving trams are the third most common type of accident in intersections with tramway. However, it is the rear-end accidents which are the most prominent in intersections with tramway, followed by collisions between pedestrians and a vehicle.

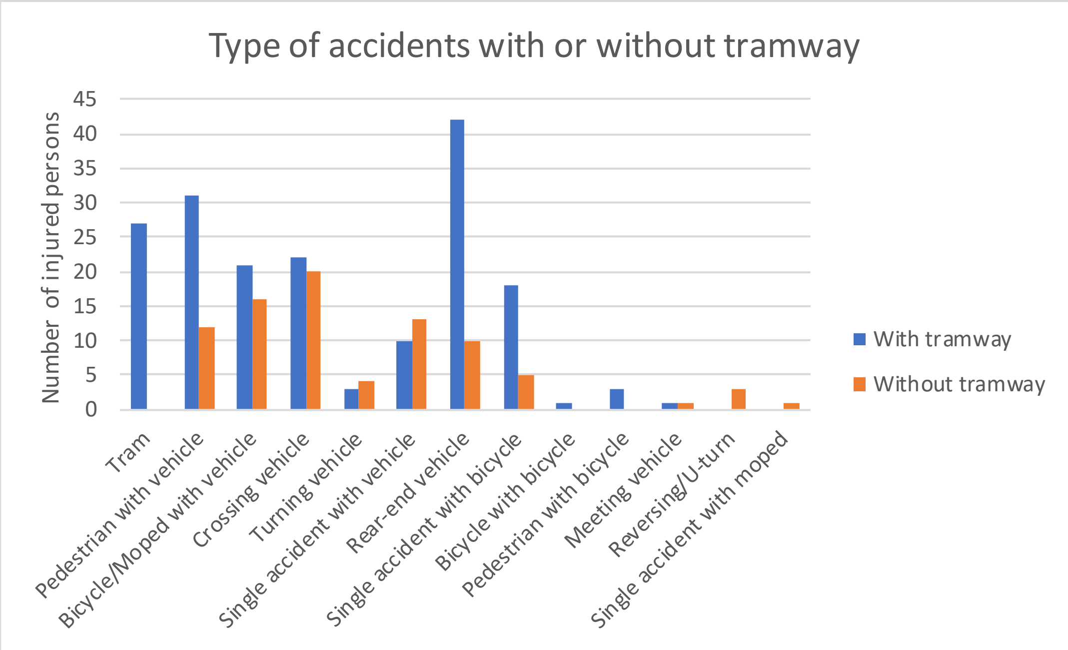

Figure 19 *Number of injured persons depending on if a tramway is located in the intersection or not. The figure is based on information from Strada. Author's own copyright.*

When analysing the accidents thoroughly in Strada it can be found that 29 out of 150 accidents in intersections with a tramway involved the tramway rail or the tram vehicle. This means that 16% of the accidents that occurred in an intersection with tramway occurred in conflict with the tram or the tramway rail.

Considering the intersections without a tramway it is notable that other accidents are more common. In these intersections, crossing accidents and bicycle/moped in collision with vehicle have resulted in the most injured persons. Overall, intersections with tramway have more accidents in total than the ones without (179 versus 85).

6.2.2 Accidents in signalized and non-signalized intersections

In signalized intersections rear-end accidents is the type of accident that has resulted in the most injured persons, Figure 20. For the non-signalized intersections crossing accidents and bicycle/moped with vehicle accidents have resulted in the most injured persons, Figure 21. The total number of accidents with injuries in the signalized intersections is 238 while in the non-signalized it is 26. However, it is important to notice that only six intersections are non-signalized in this study, Table 2 in Section 4.1.

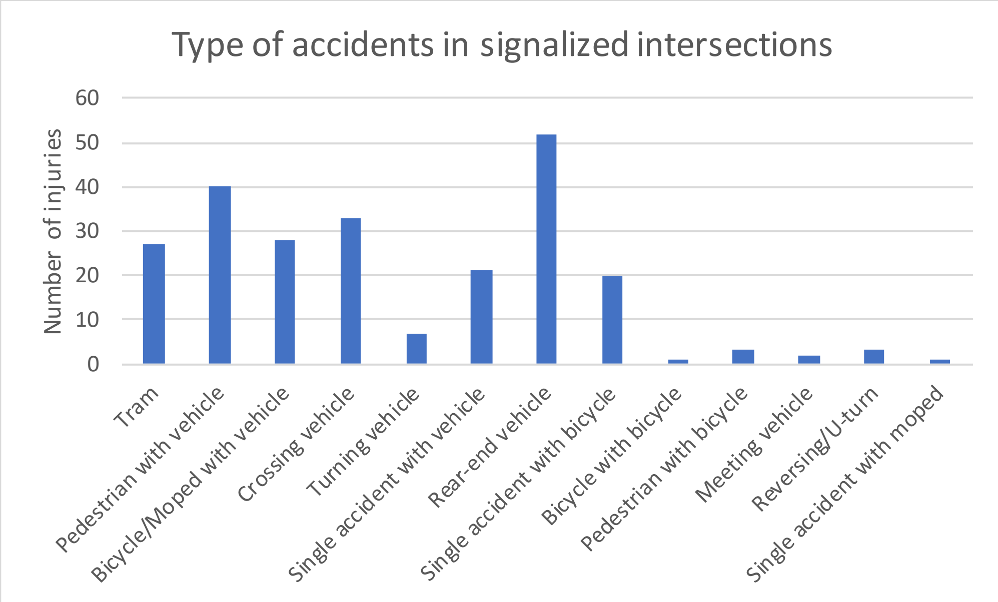

Figure 20 *Number of injured persons in signalized intersections. The figure is based on information from Strada. Author's own copyright.*

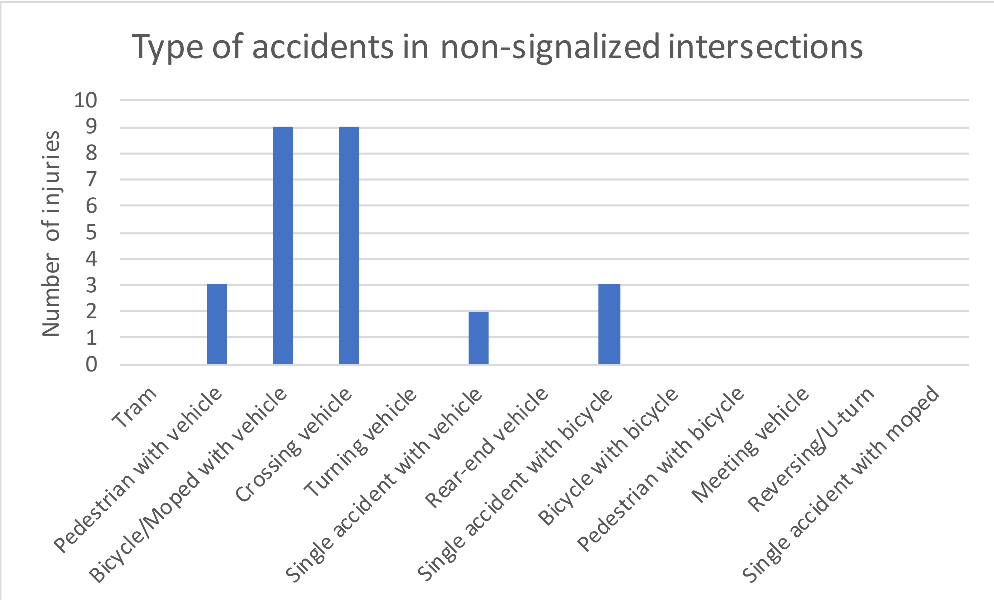

Figure 21 *Number of injured persons in non-signalized intersections. The figure is based on information from Strada. Author's own copyright.*

6.2.3 Accidents in intersections regarding the flow

It can be seen that ten of the intersections have an AADT lower than 10 000 and the other ten have an AADT higher than 10 000, Table 3 in Chapter 5. An assessment is done to compare what types of accidents tend to occur in intersections with higher versus lower AADT. In intersections with an AADT higher than 10 000 it is the rear-end accidents that is the most common accident to occur, Figure 22. For the intersections with an AADT lower than 10 000 it is, on the other hand, crossing accidents which have resulted in most injuries.

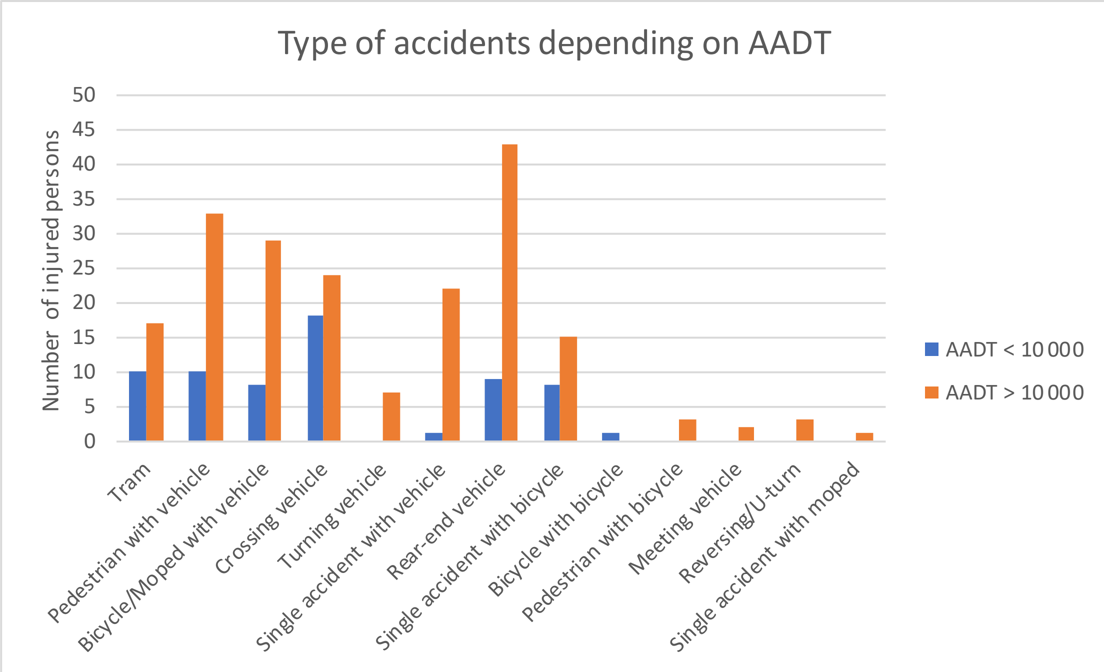

Figure 22 Number of injuries depending on AADT. Author's own copyright.

In Figure 22 it is found that it has occurred several more accidents with injuries in the intersections with higher flow, a total of 199, than for the intersections with lower flow where the number of injuries is 65. This means that in total 75% of all accidents in the investigated intersections occur in the intersections with AADT higher than 10 000. In the intersections with lower AADT it is also significant that there have not occurred any fatal or severe accidents, meaning that all of those with a higher severity level have occurred in the ten intersections with the highest flow, Table 3 in Chapter 5.

7 Improvement proposals

The analysis done in Chapter 6 shows that the types of accidents which are most common to occur in Gothenburg for the investigated intersections are rear-end, crossing, pedestrian with vehicle, bicycle/moped with vehicle and tram. In order to reduce these accidents general improvement proposals will be presented in this chapter, following by a more detailed proposal for one of the investigated intersections. Which intersection to analyse for each type of accident is based on where the type of accident has occurred most times during the examined 10 years. The improvement suggestions are focused on improving the types of accidents with injuries that most frequently occurs according to Chapter 6. In this part of the study all of the injuries were considered, including mild, moderate and severe. Since there was not enough data when excluding the mild injuries.

When presenting the improvements for the intersections the legs of the intersections are named as north, east, south and west, where the north leg is marked in the figures. However, the north leg may not always be in the correct direction according to the compass.

7.1 Rear-end and crossing accidents

The rear-end accidents are the most common accidents for the investigated intersections. This type of accident often occurs at traffic signals where the driver does not comprehend the speed of the vehicle in front, or if it stands still, and a collision between the vehicles in the same direction occurs. It is therefore suggested to increase the awareness for the drivers on the road. In order to do so rumble strips before the traffic signals is an option since the drivers then becomes more observant of the upcoming traffic situation.

The crossing accidents occur when two vehicles cross each other’s paths. These accidents often occur due the drivers having too high speed before the intersection and/or does not pay full attention to the road and are therefore not observant or able to react in time. From Section 6.2.2 it can be seen that most of the crossing accidents occur in intersections that are not signalized. Therefore, it would be a good idea to have signalized intersections in order to reduce this type of accident. Also sight improvements are an option since it would make it possible to see obstacles earlier and react in time. However, since it also can have an opposite effect it is not optimal since the speed may increase with a better sight. It is therefore possible to increase the sight and at the same time minimize the width of the lanes in order to force the driver to feel like the speed is increasing. By using this method, a better sight is forced but does not consent to a higher speed. Rumble strips are also a good option to prevent crossing accidents since it reduces the speed and makes the driver more attentive of the traffic situation.

From the investigated intersections it is seen that intersection 7, Södra Vägen/Engelbrektsgatan, is the most affected intersection considering both rear-end and crossing accidents. In this intersection, 16 out of 26 accidents had injuries related to the types rear-end and crossing, Appendix IV. Since most of the accidents of this types occurred in this intersection improvement suggestions were conducted for intersection 7.

7.1.1 Intersection 7 - Södra Vägen/Engelbrektsgatan

The intersection is located in central Gothenburg with the main street Kungsportsavenyen parallel to Södra Vägen. The tramway rail is located in between the lanes in the middle of the street and passes from south to west in each direction, Figure 23. The incoming legs have different number of lanes where east and south have one incoming lane while north has three and west has two. There is an incoming bus lane in the north and south leg, with the bus passing the intersection in both directions. The drivers on the south leg is only allowed to turn right to the east leg in the intersection, also the east leg is only allowed to drive straight through the intersection.

Figure 23 Map over intersection 7 marked with bus and tramway rail in orange and road in green. Theoretical conflict points marked by black circles for private vehicle-private vehicle conflict and black squares for private vehicle-public transport conflicts. Figure adjusted from Google maps (2019).

There are in total 16 accidents with injuries that have occurred in this intersection with the type of accident “rear-end” and “crossing”. The rear-end accidents occurred most often at the traffic signals where the vehicle in front was standing still. The crossing accidents occurred due to a vehicle crossing the intersection and colliding with another vehicle, which most often had a red light. From the information in Strada and observations at the field study it is notable that there were long queues at the traffic signals which can be a reason for the rear-end accidents. From the field study it can also be assumed that rear-end accidents can occur when vehicles are turning and have to yield for cyclists and pedestrians. The vehicle behind may not perceive the cyclist or pedestrian and therefore collide with the vehicle in front which has slowed down for the unprotected road user.

Figure 23 shows the conflict points between vehicles where it is notable that most of the conflict points are between private vehicle with public transport. However, according to Strada the majority of the accidents occur between private vehicles which means that those conflict points are of greater importance to consider when suggesting improvements. The rear-end accidents which, according to Strada, occur at the traffic signals are not shown in the figure since there are no theoretical conflict points between vehicles in the same direction.

To increase the awareness, rumble strips before the intersection in each incoming leg could be a good option in order to get the drivers to pay attention to the traffic situation and also lower the speed in time before the intersection. The rumble strips could therefore prevent the rear-end accidents. Another improvement suggestion is to regulate the different flows by having green light for cyclists and pedestrians before the vehicles. This is to avoid accidents which may occur due to the vehicles yielding for unprotected road users when turning.

Considering actions in a larger scale a roundabout would probably lead to fewer accidents, especially fewer of the type “crossing”. The effect on the rear-end accidents is more uncertain. However, a roundabout in this intersection could be difficult to implement due to multiple reasons. The physical space of a roundabout must be carefully evaluated due to the limited area.

Since the crossing accidents most often occur due to a vehicle driving against a red light, improvement suggestions for this type of accident is difficult to provide. If all road users follow the traffic rules this type of accident should not occur in the intersection. According to M. Junemo (personal communication, April 4, 2019) it is not possible to rebuild an intersection to decrease these types of accidents, and thereby it is the police who has the responsibility to find those who do not follow the traffic rules.

7.2 Accidents between pedestrian and vehicle

From the investigated intersections 43 injuries were classed as the type of accident “pedestrian with vehicle” with nine of them being of a higher severity level than mild. This makes this type of accident the second most common accident for the investigated intersections and the most common type of accident when excluding mild injuries. Therefore, this type of accident could be considered as one of the most dangerous why focus to reduce this type of accident in intersections should be done. Improvements to reduce the speed of the vehicles crossing the intersections is a way of preventing these accidents to occur, since the vehicles can stop in time and perceive the traffic situation better.

The concept of speed secure passing involves measures to reduce the vehicles speed. Speed bumps constructed before the intersection helps lower the speed of the incoming vehicles. Other methods for a speed secure passing are to install camera surveillance or dynamic speed bumps. These will reduce the speed of those who are driving too fast but does not affect drivers who follow the speed limit. A raised intersection highlights the intersection and the unprotected road users for the drivers and is also an action to reduce the speed of the vehicles. If the accidents between the pedestrians and vehicles occur outside of the zebra crossings, channelization with railings can be a way of separating the different transport modes. The railings stop pedestrians to cross in unsafe places and diverts them to the zebra crossings instead. The zebra crossings can be a danger if they are very long since it requires a long time to cross for the pedestrians. Raised traffic islands separates the zebra crossings and makes it possible to cross the intersection in two steps which is safer for the pedestrians.

From the investigated intersections it is seen that intersection 4, Skånegatan/Levgrensvägen/Bohusgatan, is the most affected with the type of accident "pedestrian with vehicle", Appendix IV. Improvement suggestions are therefore presented for this intersection.

7.2.1 Intersection 4 - Skånegatan/Levgrensvägen/Bohusgatan

The intersection is located close to the arena Ullevi in central Gothenburg. The tramway rail passes, in each direction, from north to south and is located between the lanes in the middle of the street with tram stops in the north and south leg, Figure 24. Each incoming leg has two to three incoming lanes to the intersection.

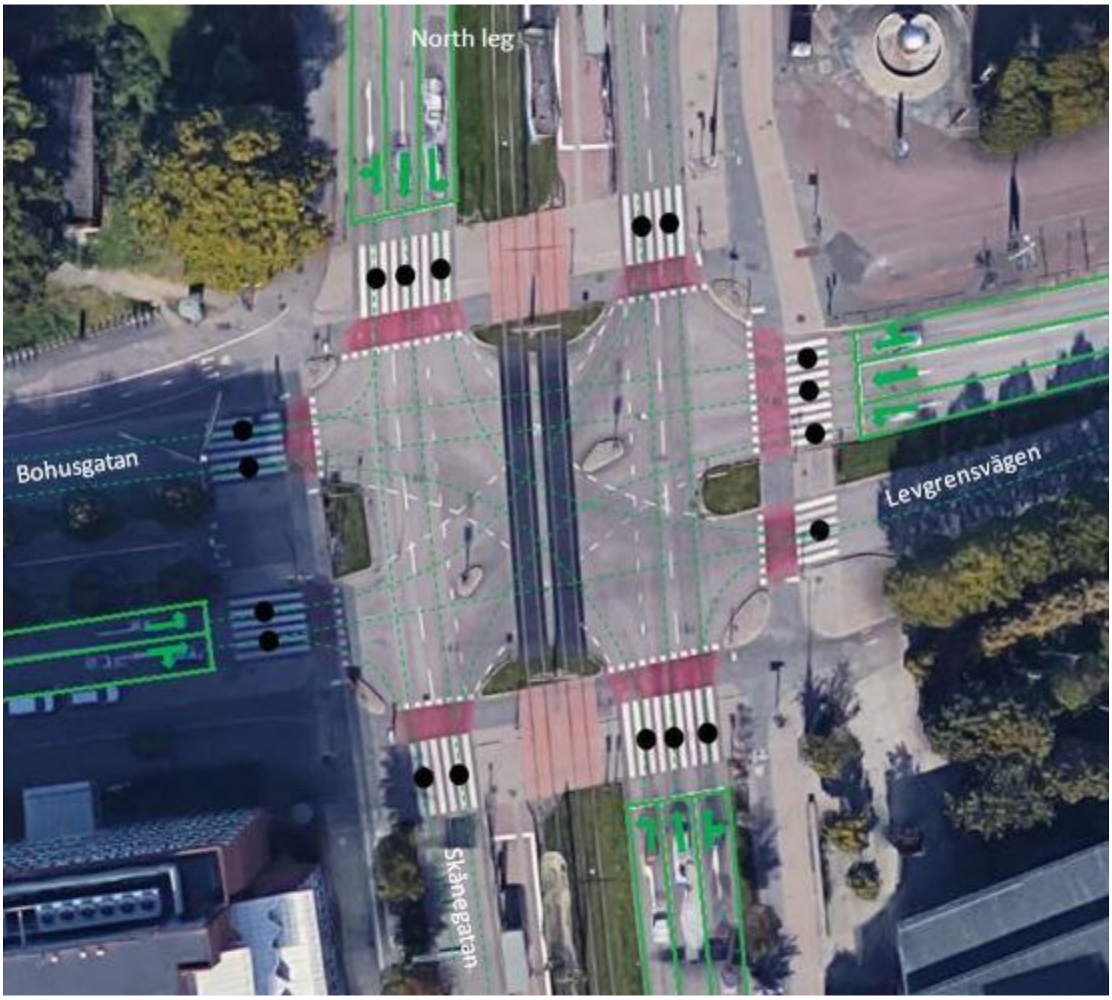

Figure 24 Map over intersection 4 marked with incoming legs in green. Theoretical conflict points marked by black circles for vehicles in conflict with pedestrians. Figure adjusted from Google maps (2019).

In this intersection ten out of 21 occurred accidents with injuries were of the type "pedestrian with vehicle". According to Strada, the accidents occurred due to either the vehicle or pedestrian did not follow the traffic rules and drove/walked against a red traffic signal. All of these accidents occurred at a zebra crossing. Therefore, it is reasoned that improvements needs to be done in connection to the zebra crossings and the traffic signals.

From the field study it was seen that many of the pedestrians that crossed the intersection at the zebra crossings walked against a red light, which means that there can be an oncoming vehicle which they do not perceive. It was also notable that the traffic signals are red for a long time which means that some of the vehicle drives against yellow in order to not get stuck behind the traffic signals in the intersection. The long red time were perceived for all transport modes. It was seen at the field study that not all pedestrians have enough time to pass the zebra crossing from when it turns green to when it turns red since the zebra crossing is very long. This means that some pedestrians need to stop in the middle of the intersection, at the traffic island, in order to wait until it turns green again. It was also seen that pedestrians do not follow the traffic rules and runs over the zebra crossings in order to save time.

From the field study and the analysis in Strada it can be concluded that it is not the design of the intersection that leads to the injuries due to collision between vehicles and pedestrians, but the decisions made by the persons walking or driving. Actions to reduce the number of accidents between pedestrians and vehicles in this intersection is therefore focusing on how to change the behaviour of the road users and less on the physical design of the intersection. By changing the behaviour, it is desired to stop people from walking and driving against a red light. In this case the behaviour of braking traffic rules needs to be taken care of which is the police responsibility.

One option is to change the traffic lights to shorter green time for vehicles and thereby pedestrians do not save as much time by illegally passing the zebra crossing. However, this might be a worsening for the vehicles since it takes longer time to get past the intersection. It also can contribute to irritation and may affect the drivers' attention since a longer waiting time can lead to distraction. Furthermore, it is possible to insert traffic signal countdown timers for the pedestrians, Figure 25. These types of traffic signals show how many seconds there are left until the pedestrians are allowed to pass the zebra crossing. By implementing this type of traffic signals the pedestrians may get more comfortable while passing the zebra crossings since they do not have to rush over it, depending on how much time there is left. It might also have the effect that the pedestrians see that they do not need to illegally cross the zebra crossings since there are just a few seconds left until they are allowed to cross.

Figure 25 *Traffic signal countdown timers for pedestrians implemented in Oslo, Norway. Author's own copyright.*

It can be of great importance to reduce the speed of the vehicles by inserting speedbumps, especially along Skånegatan since it was discovered from the field study that the vehicles have a high speed on this road. By reducing the speed it is expected that the severity of the injuries decreases. However, speed reducing measures such as speedbumps would probably affect the availability of the road since the road is fairly well trafficked.

7.3 Accidents between bicycle or moped and vehicle

37 injuries from the investigated intersections are categorized as bicycle or moped in conflict with vehicle. Six of these are of higher severity level than mild. This category includes both cyclists and moped riders, but in the investigated intersections 34 of the 37 injuries were concerning a cyclist. One of the injured was a moped rider and two of the injured were the drivers of the vehicles. Improvement suggestions are therefore aiming to address the cyclist's safety.

Safety improvements for cyclists can be to improve the visibility of the cyclists for the vehicle drivers and/or to separate the flows of cyclists and vehicles. A way of improving the visibility of cyclists is to set up an advanced stop line, also known as bike box, for the cyclists. This will make the cyclists more visible for the drivers and thereby reduce the accidents caused by inattentive drivers. A method for reducing this type of accident is by having separated bicycle flow and vehicle flow. This can be done by separation with railings or, in a more advanced way, with construction of a bike overpass or underpass. The overpass or underpass enables crossing of the intersection without conflict points with vehicle traffic and can be shared with pedestrians.

From the investigated intersections 14 out of 20 had at least one injury related to the type of accident bicycle/moped with vehicle, Appendix IV. Since the intersection with most of this type of injury (number 18 in the tables) has already been rebuilt with improvements affecting cyclists it was chosen to give improvement suggestions regarding intersection 14, Nya Allén/Kungsportsavenyen.

7.3.1 Intersection 14 - Nya Allén/Kungsportsavenyen

The intersection Nya Allén/Kungsportsavenyen is located central in the city. The tramway passes through Kungsportsavenyen where only buses and trams are allowed in the south leg, Figure 26. The traffic on Nya Allén is one way and goes from east to west. There are bicycle paths in every leg of the intersection, two way in the west-east direction and one way in north-south direction. The theoretical conflict points involving cyclists with vehicles are marked in the figure.

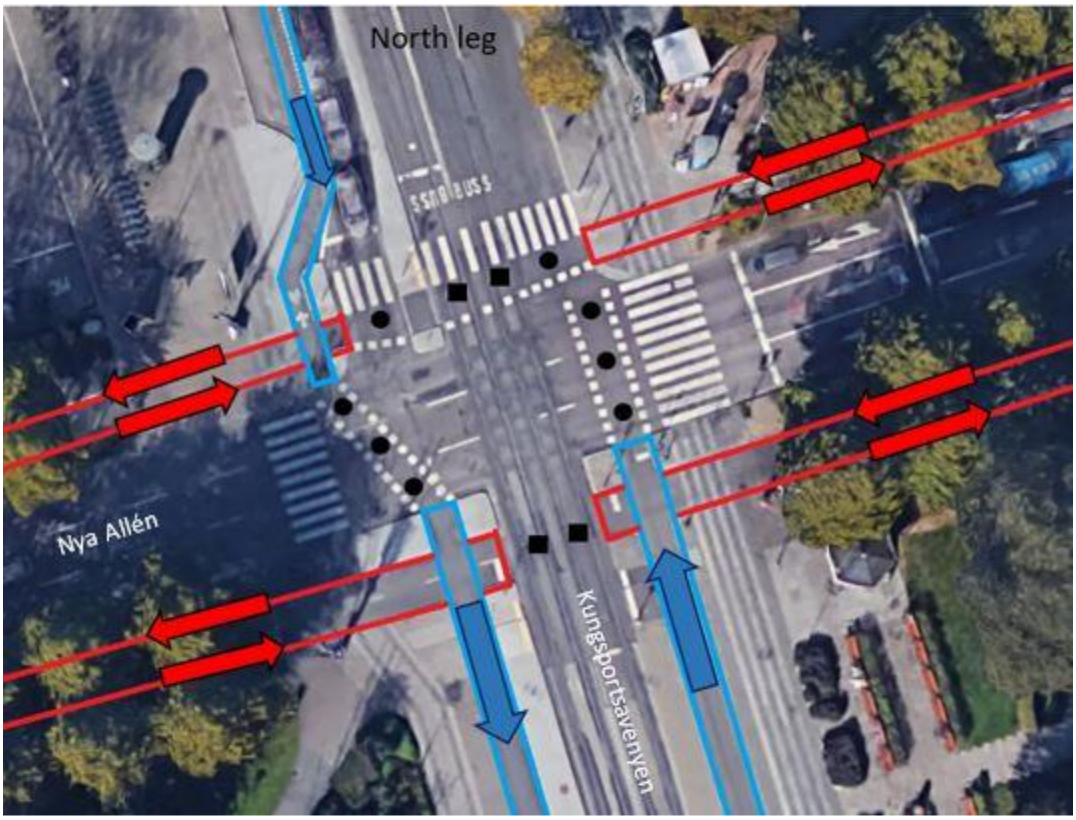

Figure 26 *Map over intersection 14 marked with one-way bicycle paths in blue and two-way bicycle paths in red. Theoretical conflict points marked by black circles for bicycle-private vehicle conflict and black squares for bicycle-public transport conflicts. Figure adjusted from Google maps (2019).*

In this intersection four injuries occurred due to cyclists in conflict with vehicles. From Strada it can be discovered that all of them were occurring when both vehicles and cyclists had a green signal and the vehicle was turning in the intersection. Two of the injuries occurred involving a private vehicle, one with a bus and one with a light truck.

From the analysis in Strada and observations from the field study it is seen that it is the turning vehicles that are the problem considering the type of accident bicycle/moped with vehicle. According to the Traffic Regulation (SFS 1998:1276, chapter 3, §60), it is the vehicle drivers' responsibility to give way for cyclists and pedestrians when both traffic lights are green and the vehicle is turning in the intersection. Assuming that the drivers aims to follow the traffic rules and laws, it is thereby also assumed that the drivers does not perceive the cyclists when turning. Improvement suggestions for this intersection is therefore focused on increasing the visibility of the cyclists for the drivers.

To increase the visibility of the cyclists for the drivers warning signs for cyclists can be put up in the vehicle lane. By inserting warning signs, the drivers pay attention to the cyclists crossing the road which can prevent accidents to occur.

An advanced stop line for cyclists can be used in this intersection to increase the visibility of the cyclists. The bicycle path on the north leg, Figure 27, is a good place for a bike box since the only way to drive for private vehicles is to the right. Having a bike box in this lane will probably increase the awareness of cyclists and thereby decrease the risk of collision between cyclists and vehicles.

Figure 27 *North leg of intersection Nya Allén/Kungsportsavenyen. The red marking represents the area where the bike box should be placed, by withdrawing the stop line for vehicles and making the cyclists stop in front of the vehicles. Author's own copyright.*

Since this intersection only has two legs with incoming private vehicles and the bicycle paths are separated from vehicle traffic in most cases, the north leg is the only leg which is appropriate for a bike box.

In addition to the bike box the bicycle crossings should be marked by having different colour. This is to increase the awareness of cyclists at the bicycle crossings. The markings should be placed according to Figure 28. Marking over the tramway can lead to false safety for cyclists and unsafe decisions to cross the road, especially if a tram is approaching. However, since there are traffic signals in the intersection this should not be a problem if the cyclists follow the traffic signals. The marking of the bicycle crossing is advantageous since there are vehicles turning from Nya Allén which needs to be aware of the cyclists. Also, a kerbstone in the old bicycle path is needed in order to prevent the cyclists to go straight forward in the bicycle path instead of using the bike box. By inserting a kerbstone, it is only allowed to turn left or right when using the bicycle path and the bike box is used in order to go straight forward in the intersection.

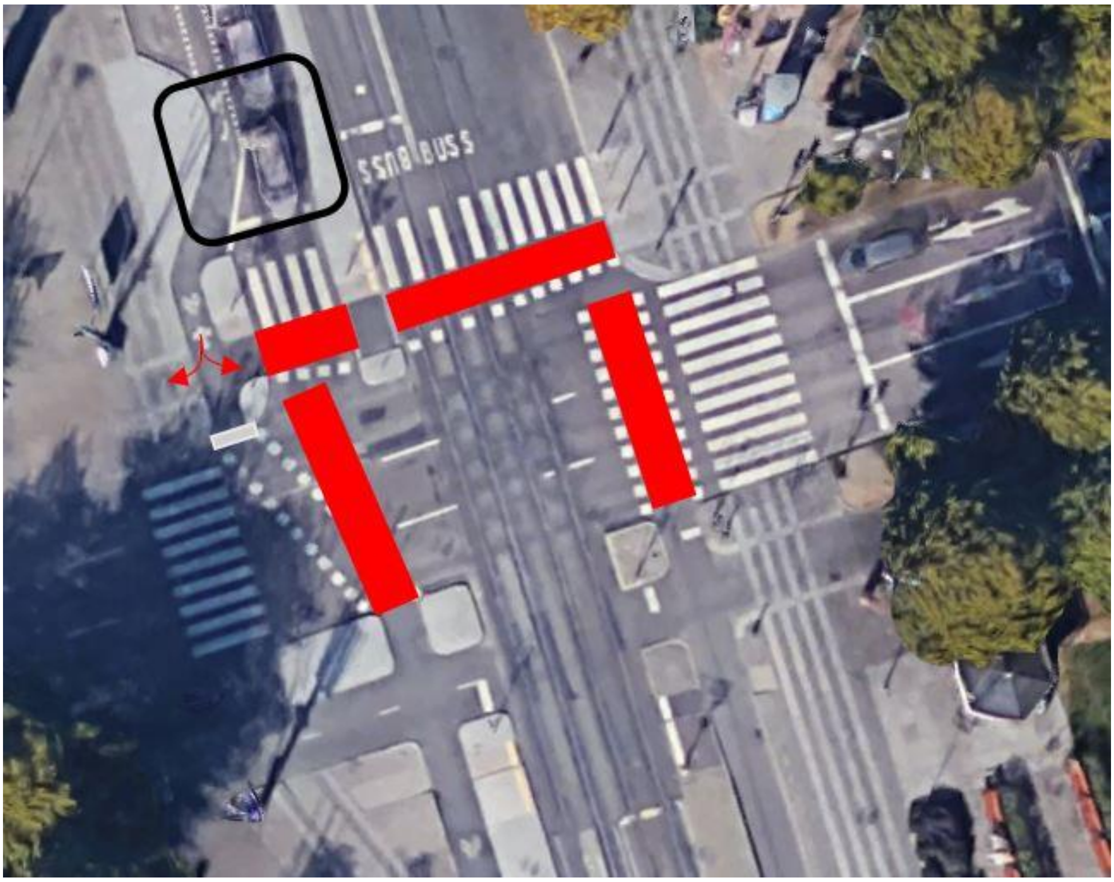

Figure 28 Improvement suggestions for intersection 14. The black box indicates the place of the bike box and the red markings the area of coloured bicycle crossings. Also, the grey marking is the kerbstone and the arrows is how the cyclists can turn if they are not going straight forward in the intersection. Figure adjusted from Google maps (2019).

7.4 Accidents involving tram

From the investigated intersections 27 accidents with injuries were classed as the type of accident “tram”. Five out of these injuries were of higher severity level than mild. This makes this type of accident important to consider since the tram is an additional conflicting vehicle in the intersections. From Table 2, in Section 4.1, it is seen that ten out of the investigated intersections includes a tramway, where seven of them have accidents with injuries occurring in connection to the tram. The injuries that have occurred with tram is pedestrians who were in collision with the tram or a collision between tram and motorized vehicles or cyclists. Many of the accidents with injuries that involves a motorized vehicle occurred due to the vehicle turning and presumably not noticing the oncoming tram.

When considering safety for pedestrians, channelization with railings can reduce the number of accidents. The railings stop the pedestrians to cross the road in unsafe places and leads them to the zebra crossings instead. It also prevents the pedestrians from running out on the road in order to catch the tram which in turn means that the possibility of being hit by a vehicle decreases. The pedestrians also get more attentive of the traffic situation when there is a railing in their way since they cannot cross the road in unsafe places.

In order to reduce the number of accidents with injuries between the tram and motorized vehicles traffic signals might improve the number of accidents occurring. By using traffic signals for each transport mode the accidents decreases since all road users becomes more attentive of the situation. However, all of the investigated intersections with tramway have traffic signals and it is therefore preferable to do other improvements as well. For the vehicles it is possible to use speed secured passing in order to reduce the speed of the vehicles, for example a speed bump before the intersection would make it safer for the drivers since that affects both the speed and how observant the drivers are.

To reduce the number of injuries connected to the tram a separation between the tram and the other transport modes may improve the traffic safety. By separating the tram from the other transport modes the number of conflict points decreases which in turn theoretically leads to less accidents connected to the tram. A separation can also be visual, for example by having different colours and markings on the road, in order to visually separate the tramway rail from the other transport modes. This does not decrease the number of conflict points, but increases the attention of the drivers. However, it is also important to thoroughly investigate where the tram would be located in order to have a situation that is safe for all transport modes. When having the tramway in the middle of the road railings may reduce the number of accidents with injuries.

Seven out of the investigated intersections have at least one tram related accident. Intersection 19, Torgny Segerstedtsgatan/Fågelvägen, has the most accidents of this type and improvement suggestions for this intersection, with regard to reduce the tram related accidents, is therefore presented.

7.4.1 Intersection 19 - Torgny Segerstedtsgatan/Fågelvägen

Torgny Segerstedtsgatan/Fågelvägen is located in the west side of Gothenburg, outside of the most central parts of the city. The area around the intersection is mostly residence houses, schools and local stores. The tramway is placed along Torgny Segerstedtsgatan separated from the road, Figure 29. There are two tram lines passing the intersection and in rush hour (7 – 8 AM) the trams pass in an interval of approximately five minutes in each direction. However, the accidents with injuries were occurring either at noon or in the afternoon. At these times the trams pass in an interval of approximately 10 minutes in each direction.

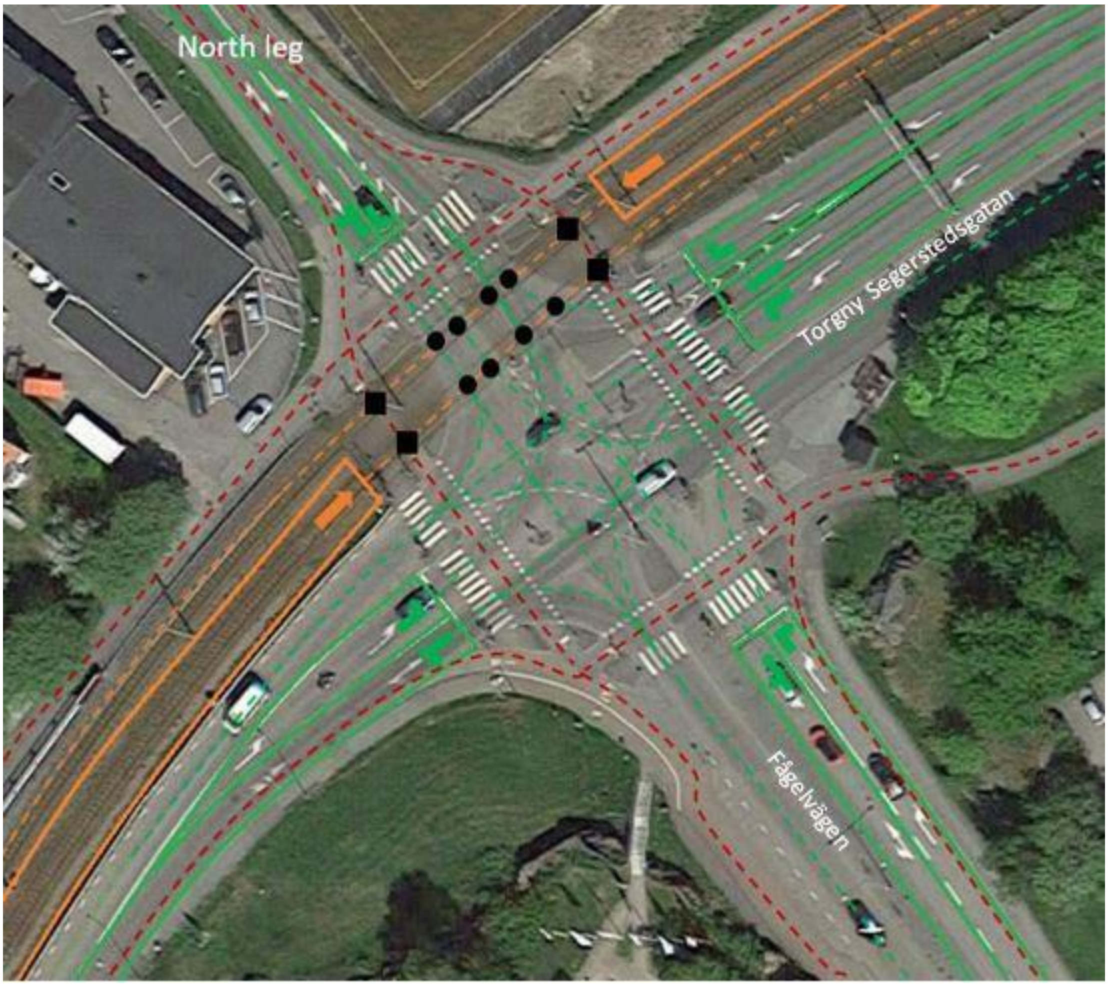

Figure 29 Map over intersection 19 marked with tramway rail in orange, road in green and bicycle path in red. Theoretical conflict points marked by black circles for vehicle in conflict with tram and black squares for bicycle in conflict with tram. Figure adjusted from Google maps (2019).

The type of accident "tram" was the most common type of accident in this intersection with nine out of 19 accident being of this type. The accidents are either a collision between tram and vehicle, tram and cyclist or tram and moped. No accidents between pedestrians and trams were found in Strada for this intersection. It is not clear from the information in Strada how these accidents occurred, and it is also unknown which transport mode had to give way at the time of the accidents. However, from the field study it was noticed that when a tram was approaching the other transport modes had to give way automatically and that the tram was often driving relatively fast in the intersection. It can be assumed that the drivers and/or cyclists did not perceive the oncoming tram and therefore the collision occurred.

From the field study it was seen that there are some safety improving measures in the intersection, there are for example railings separating the tramway rail from other transport modes. There are also warning sounds when a tram is approaching and on the east leg of the intersection there is a warning sign for oncoming trams, Figure 30.

Figure 30 Intersection seen from the east leg, including with a warning sign for the trams. Author's own copyright.

The sight is good in the intersection and the intersection is open with wide lanes. Even though the intersection has good sight it can cause drivers to not perceive the tramway rails and a possible oncoming tram, see example in Figure 31. Improvement suggestions for this intersection are therefore focused on increasing the awareness of the tram when it is approaching and the tramway rail for vehicles and cyclists.

Figure 31 Picture of the intersection from the corner between south and west legs. From this perspective it can be difficult to perceive the tramway rail. Author's own copyright.

Safety improvements for preventing collisions between a tram and vehicle and/or cyclist in this intersection are aiming to bring attention to the trams and make other transport modes yield for them. To achieve this, signs as the one in the east leg should be placed in all legs of the intersection. Flashing light signals, which starts to flash when a tram is approaching the intersection, should also be implemented to warn the other transport modes for the oncoming tram. The tramway should also be made more distinctive by marking the tramway area with markings on the road, a common way is to have lines marking the tramway area, and/or by a different coating of the road in the tramway area. The improvement suggestions are presented in Figure 32.

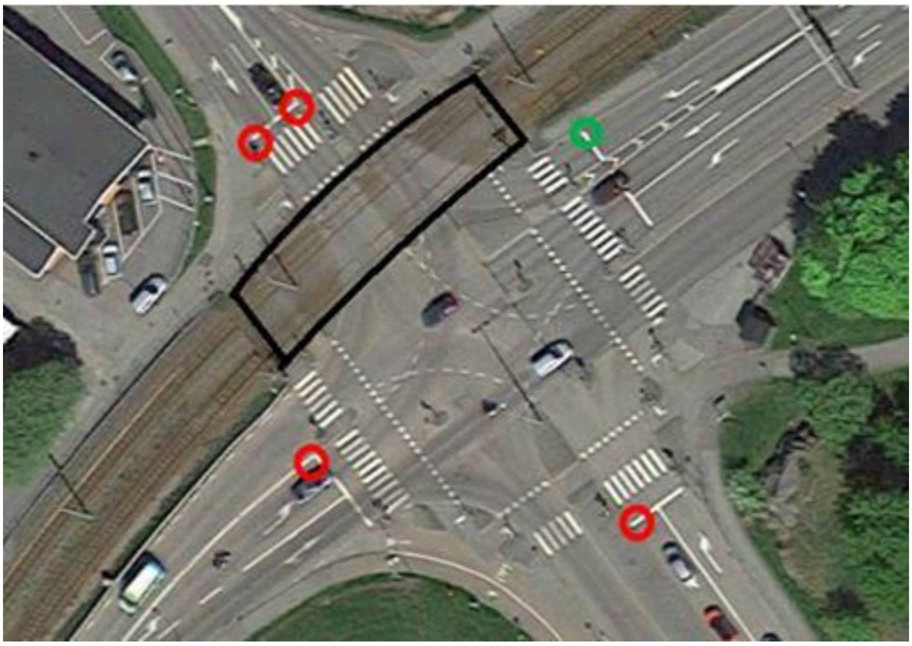

Figure 32 *Improvement proposal for intersection 19. Black area represents the area of marking the tramway tracks with lines and different coating. Red circles are where warning signs for trams should be placed and green where the existing sign is located. Figure adjusted from Google maps (2019).*

8 Discussion

This chapter includes a discussion of what could have an effect on the result of the study. Followed by further investigations that can be done.

8.1 Limitations

The limitations made in this study are specified to the geographical area Gothenburg and roads with the speed limit 50 km/h in order to narrow down the number of possible intersections for investigation. By further narrowing it down to only consider 4-legged intersections is a way of specifying the problem to a specific type of intersection even if the design of the intersections may differ. This study only includes 20 different intersections in Gothenburg, in order to get a more reliable result more intersections should be investigated.

By not considering the flow of the pedestrians and cyclists a comparison with the vehicle flow is not applicable. It is possible that a high flow of pedestrians and cyclists contributes to more accidents. With a higher flow of unprotected road users there is a greater probability that a collision between unprotected road users and vehicles occur. In the investigated intersections it is therefore possible that the intersections with many accidents also have a high flow of pedestrians and cyclists.

The weather and other external factors such as day or night time is not considered in this study, since the aim of the report is to investigate the relation mainly between flow, safety and design of the intersections. It can be assumed that the external factors have an influence on at least some of the accidents occurring in the investigated intersections. However, the information available in Strada is not sufficient for this type of study and it is therefore reasoned to neglect the external factors.

Another significant limitation is the economy aspect. The costs for the improvement proposals are not considered in this study since it would affect which improvements that are suggested. The economy is one of the key factors when deciding on safety improving actions and changes to the road network. However, from this report it is seen that many of the suggested actions for improvements can be assumed to be economically favourable such as road markings and warning signs. The larger scale actions, such as rebuilding an intersection, are probably very expensive. When planning in early stages there is great uncertainties regarding the final economical cost. If actions such as rebuilding an intersection into a roundabout is in question, more data is needed and an economical evaluation should be done in later stages.

8.2 Method

Choosing which intersections to include in the study was dependent on if there was information about the AADT in each leg of the intersection. More intersections could have been included if the flow was not considered. This would give a more reliable result of which accidents that are common to occur in intersections. There has been no consideration to if the intersections have been rebuilt during the time span of the investigated accidents when analysing the accident statistics. This could be somewhat misleading when analysing the intersections, for example there could be a situation of many accidents occurring ten years ago and improvements were done which decreased the accidents. In this case the intersection would appear as an intersection in need for improvement, but in fact no accidents have occurred in the rebuilt intersection. However, when choosing which intersections to propose detailed improvement suggestions to, recent known rebuilding of intersections was considered. For example, intersection 18, Delsjövägen/Töpelsgatan/Birkagatan, and intersection 9, Mölndalsvägen/Sankt Sigfridsgatan/Fredrikdalsgatan, was actively not chosen for detailed improvement suggestions due to recent rebuilding and improvements of them.

The AADT that was taken from the Traffic and Public Authority in Gothenburg may not be entirely reliable. This is because there is no information regarding how and where on the road the measurements have been taken. Also, the measured AADT is sometimes produced for a road between two bigger intersections. This means that there can be connecting roads along the measured stretch, which is also seen for some of the investigated intersections. That in turn means that it can be inbound and outbound vehicles at the connecting roads which not passes the whole stretch and are thereby not counted in the AADT. The AADT can therefore be lower or higher in the intersection due to the connecting roads.

The AADT values were measured at different years which means that a calculation was needed in order to obtain the AADT for 2018. The used factor to calculate the traffic increase was 1,29 which means that the AADT remarkably increases when calculating how much the traffic will increase in just a few years. This is not reliable since the amount of traffic flow variates from year to year. However, this gives an overview of how many vehicles that passes the roads on an average day. It is also important to consider that the factor 1,29 is produced for the whole metropolitan area of Gothenburg, including municipalities outside of the city. The increase of traffic probably is lower in central Gothenburg. The calculated AADT of the incoming flow, for all of the four legs, is divided by two. This is based on the assumption that there is the same amount of inbound as outbound vehicles during a day in each leg.

The accident statistics was taken from Strada for a period of ten years but the AADT was obtained for one year. This means that there could be a year with more accidents depending on how high the flow has been, since the flow in the intersections has changed during the 10-year period. Since the AADT was taken from the latest measurements and then calculated for 2018 it is assumed that the intersection has had the same flow the last ten years which is not likely.

8.3 Strada

The accidents that are reported in Strada includes all accidents that have occurred in the road system. An accident that has occurred can include more than one injured person which means that there may not be an excessive number of accidents occurring in an intersection, but there can be many injured persons. This means that even if many persons are injured in traffic the number of accidents may not be many.

The information in Strada can be challenging to analyse since there are not a lot of information and not long descriptions of the events leading up to the accident. Since the events leading up to the accidents most often are not complete some assumptions concerning the causes of the accidents are needed. The improvement proposals are based on these assumptions and can thereby be affected if the assumptions about the events of the accidents are not completely accurate. When retrieving the information for a specific intersection in Strada the accidents sometimes have occurred outside the specific area. This means that it is possible that some accidents with injuries that have occurred in the investigated intersections have not occurred exactly in the intersection. Even if this was analysed and thoroughly investigated some errors may occur in the data.

Since persons that have been injured in the intersections can report the accidents through the emergency hospitals the information of the time of the accident, events leading up to the accident and other important factors may not be correct. This because the injured persons may not have paid any attention to the weather etc. It is also noted that the persons that are registered by both police and emergency hospitals can sometimes occur twice in Strada which means that one injured person are calculated as two. This is however an error in Strada since it should be compiled into just one injury. Despite the possible errors, Strada is a good tool to find out which accidents that occur and what severity level the accidents have in order to know what actions for improvements that needs to be considered.

8.4 Accidents in intersections

The number of accidents with injuries that has occurred for each intersection is not significantly high since some of the intersections do not have many injuries. Therefore, it might not be reasonable to take the occurring accidents with injuries as a general assumption when considering the accident statistics for the intersections. It is on the other hand a good guideline of which types of accidents that mostly occur in intersections in Gothenburg.

The severity levels of the accidents with injuries are in Strada labelled as mild, moderate, severe and fatal. The mild injuries are excluded in some of the figures since the injuries are considered not to be as critical as the others. The result changes depending on if the mild injuries are considered or not and the result may be different if those are considered. The accidents concerning the pedestrians that are in single accidents are not considered since they are not related to the traffic accidents. Most often the accidents with pedestrians in single accidents are persons who have fallen at the pedestrians walk. Also, the single accidents with bicycles are most often accidents where the cyclists have fallen due an obstacle in front which most of the time is not related to the design of the road and the traffic situation. These accidents should therefore be carefully evaluated in order to include them in the accident statistics.

In this study, the number of injured persons is considered and not the number of accidents. By only considering the number of injured persons it is possible that many of the injured persons where involved in the same accident. This can lead to misleading statistics when comparing intersections and the type of accidents. For example, the type of accident “crossing” and “rear-end” requires at least two vehicles to be involved in an accident and thereby often leading to many injured persons. For some intersections this can be misleading if there for example only has been one accident with many persons involved, comparing to an intersection where accidents occur more regularly but with fewer injured persons. However, since it is the injured persons which should be reduced it is reasonable to consider the number of injured persons regardless the number of accidents.

8.5 Correlation between flow and safety

From the analysis of the correlation between flow and injuries, a tendency of a trend in the correlation could be seen, with a R^2 value of 0,4617. It is not a perfect fit for a linear correlation, even though when removing the outliers, the trend becomes a bit stronger. The result from the correlation analysis should therefore be carefully considered.

A linear regression is assumed which is probably not completely accurate. This can also explain the rather weak correlation. If considering other variables than AADT and injuries the correlation would possibly be more significant. For example, variables such as the design geometrics and the weather could be considered for a more complex and possibly a more accurate correlation. Important design geometrics can be number of incoming lanes, type of traffic signals, lane width, zebra crossings length and the presence and design of bicycle paths.

8.6 Safety improvements

From Chapter 7 *Improvement proposals* where four intersections are investigated it is noted that there are other factors than design of the road that affect the traffic safety. There are several other aspects that are important to consider. For accidents that are not connected to the design other aspect should be considered in order to reduce the type of accident, if possible. For example, most of the rear-end and crossing accidents occur due to the human factor and may be reduced by using vehicles that have automatic emergency brake when approaching another vehicle in front. It is, on the other hand, only newer vehicles that have that function and it might take a while until the majority of the vehicles on the road have this function.

Since there has not been remarkably many accidents with injuries it is hard to draw conclusions and see connections for the investigated intersections. The result should probably need more investigated intersections in order to find stronger connections. However, this gives a good picture of what accidents that occur in the intersections. It is, on the other hand, very positive that not more accidents have occurred.

In this report the improvement suggestions are specifically given for four intersections aiming to reduce one type of accident in each intersection. It should be noted that the suggested actions for improvement could have a positive effect on other types of accidents as well. Some of the investigated intersections have many accidents and should therefore consider having improvements aiming to reduce all types of accidents. The improvement proposals that are presented aims to prioritize the unprotected road users since those are seen as the most severe injured in the investigated intersections.

It is a balance between safety and other parameters when designing and planning for an intersection. Traffic safety improvements which includes speed reducing measures easily have a negative impact on availability for the drivers and could be a reason for not implementing the safety improvement. Also, on larger roads the availability for emergency vehicles must be considered and is a very important and decisive factor. Another parameter which is coming of greater importance in recent years is the sustainability aspect, thereby it is also important that the improvements encourages sustainable transport modes such as walking, cycling and using public transport.

Therefore, safety improvements which also supports this should be favoured. To have an attractive urban space is also increasingly important for cities. Safety actions such as railings can be a very effective way of separating flows and transport modes but can have a negative impact for unprotected road users and leads to a less attractive urban space.

8.7 Further investigations

Further investigations are recommended in order to get a better understanding and increase the traffic safety in intersections in Gothenburg. By analysing the time period of when the accidents occur in each intersection it may be possible to find if there are any connections when the accidents occur. A continuation of the study is also to analyse the time of accidents in relation to the flow, from this it could possibly be seen if the accidents occur at times with a high flow or if the cause of accident is of other reasons. In further studies a more advanced flow and safety correlation could be conducted, where the correlation is examined to be non-linear instead of the linear correlation which is examined in this report. It is also possible to consider the conflict points for each intersection where it might be possible to find similarities between the intersections and where the accidents occur.

Correlations between capacity and accidents is also a factor that affects the traffic safety and should be analysed. An analysis of how many lanes each intersection has would also be done in order to find if it has any effect on how many accidents that occur in each intersection. Finally, to include the flow for pedestrians and cyclists in order to find a connection between the different flows and also to find out how the flow for pedestrians and cyclists affect the number of accidents that occur.

9 Conclusion

This thesis has aimed to study intersections regarding traffic safety, road design and how they are connected. The investigated intersections have been investigated in an analysis of the flow and accident statistics in order to find which type of accidents that are most common to occur in 4-legged intersections in Gothenburg.

There are several parameters affecting the traffic safety and it is notable that the parameters have different effect on the safety. The parameters include different aspects and may have an effect on the design of the road, the road users and external factors. In this study a connection between the road design and the traffic safety is seen. It is important for the design of the road to be safe for the road users, but it is not possible to design a road in order to reduce some of the parameters that affect the traffic safety. This is because the parameters that includes, among other things, the behaviour of the road users, the vehicles and the external factors is not possible to remove by rebuilding and designing a road. The design of the road is not always the problem when considering the accidents that have occurred in the intersections, most often it is the human factor that has the greatest impact of the accidents that occur.

The result from the flow and safety correlation analysis shows a trend in the linear correlation with an R^2 value of 0,4617. If removing the outliers, the R^2 value is instead 0,6717 which can be considered as a connection between flow and safety, where a higher flow results in more traffic accidents with injuries. From the assessment of intersections in Gothenburg it was also seen that when dividing the investigated intersections into intersections with AADT higher and lower than 10 000 as much as 75% of the injuries had occurred in intersections with the higher AADT. Also notable is that in the intersections with lower AADT no fatal or severe injury had occurred.

The five most common types of accidents with injuries for the investigated intersections were found to be rear-end accidents, crossing accidents, pedestrian in collision with vehicle, bicycle in collision with vehicle and trams in collision with other transport modes. When excluding the mild injuries, the crossing and rear-end accidents are no longer among the most common, instead the type of accident “single accident with bicycle” is among the most occurred. In other words, it is seen that it is the unprotected road users who are most common to be injured in traffic accidents in the intersections and they are also prone to be more severe injured.

Safety improvement proposals for the most common types of accidents were given. In many of the cases it was concluded that it is often not the design of the intersection that causes the accident. Instead it is the lack of attention and decisions made by road users. Many improvement suggestions were therefore focusing on actions to increase the attention of the traffic situation for the road users.

Finally, improvements in order to reduce the number of accidents with injuries to occur are needed. The types of accidents that occur in the investigated intersections are most often caused by the road users and not because of the design which in turn means that it is mainly the behaviour of the road users that needs to be considered and not specifically the design of the intersection.

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Appendix I: Map over the investigated intersections

Figure adjusted from Google maps (2019).

Appendix II: The calculated AADT

No.	Intersection	AADT A	AADT B	AADT C	AADT D	AADT Total	Manipulated AADT A	Manipulated AADT B	Manipulated AADT C	Manipulated AADT D	Manipulated AADT Total	AADT in intersection
1	Parkgatan/Södra vägen	11 200	3 500	9 600	3 900	28 200	11 440	3 575	9 806	3 984	28 805	14402
2	Kungsportsavenyen/Engelbrektsgatan	3 800	1 200	11 900	1 800	18 700	3 881	1 226	12 155	1 839	19 101	9551
3	Fridkullagatan/Liljeforsgatan	1 000	7 000	900	8 000	16 900	1 040	7 280	936	8 320	17 575	8788
4	Skånegatan/Levgrensvägen/Bohusgatan	2 800	16 100	3 400	14 200	36 500	2 860	16 445	3 473	14 505	37 283	18641
5	Såggatan/Amiralitetsgatan	800	2 700	1 900	2 700	8 100	861	2 830	2046	2 907	8 645	4322
6	Andra Långgatan/Värmlandsgatan	1 100	6 000	900	7 600	15 600	1 153	6 290	943	8 523	16 909	8455
7	Södra vägen/Engelbrektsgatan	11 900	6 000	12 300	7 700	37 900	12 155	6 336	12 564	7 865	38 921	19460
8	Engelbrektsgatan/Sten Sturegatan	13 000	3 200	3 700	7 300	27 200	13 519	3 269	3 779	7 592	28 159	14080
9	Mölndalsvägen /Sankt Sigfridsgatan/Fredrikdalsgatan	8 600	11 200	22 400	13 500	55 700	8 944	11 440	22 880	13 790	57 054	28527
10	Lorensbergsgatan/Kristinelundsgatan	700	500	4 500	800	6 500	728	520	4 816	832	6 896	3448
11	Olivedalsgatan/Alfhemsgatan	700	640	500	800	2 640	728	697	520	839	2 783	1392
12	Linnégatan/Nordenskiöldsgatan	2 300	4 700	2 200	8 400	17 600	2 411	4 927	2 247	8 806	18 391	9195
13	Kustgatan/Karl Johansgatan	2 500	5 300	3 200	5 900	16 900	2 621	5 556	3 355	6 185	17 716	8858
14	Nya Allén/Kungsportsavenyen	12 500	3 400	11 000	900	27 800	12 768	3 473	11 236	950	28 427	14214
15	Parkgatan/Sten Sturegatan	9 600	5 000	10 700	2 300	27 600	9 806	5 107	10 929	2 349	28 192	14096
16	Första Långgatan/Nordhemsgatan	6 200	5 300	3 300	1 500	16 300	6 499	5 414	3 371	1 560	16 844	8422
17	Härlandavägen/Stockholmsgatan/Kålltorpsgatan	6 000	2 100	5 900	1 300	15 300	6 129	2 145	6 027	1 328	15 628	7814
18	Delsjövägen/Töpelsgatan/Birkagatan	10 200	400	9 400	2 000	22 000	10 419	460	9 602	2 043	22 524	11262
19	Torgny Segerstedtsgatan/Fågelvägen	10 300	5 200	10 500	5 100	31 100	10 797	5 599	11 007	5 346	32 750	16375
20	Munkebäcksgatan/Colliandersgatan/Torpavallsgatan	2 200	22 400	9 100	18 700	52 400	2 339	22 880	9 677	19 101	53 998	26999

In the table the calculated AADT can be found under *Manipulated AADT*. A, B, C and D are the four legs in the intersection, where A is west, B north, C east and D south.

Appendix III: Type of accident depending on type of intersection

Type of accident	All injuries	Injuries excluding mild	Accidents that occured in intersection		Accidents that occured in intersections that are		Intersection with	
			With tramway	Without tramway	Signalized	Non-signalized	AADT < 10 000	AADT > 10 000
Tram	27	5	27	0	27	0	10	17
Pedestrian with vehicle	43	9	31	12	40	3	10	33
Bicycle/Moped with vehicle	37	6	21	16	36	1	8	29
Crossing vehicle	42	1	22	20	33	9	18	24
Turning vehicle	7	0	3	4	7	0	0	7
Single accident with vehicle	23	5	10	13	23	0	1	22
Rear-end vehicle	52	0	42	10	52	0	9	43
Single accident with bicycle	23	8	18	5	20	3	8	15
Bicycle with bicycle	1	1	1	0	1	0	2	0
Pedestrian with bicycle	3	2	3	0	3	0	0	3
Meeting vehicle	2	0	1	1	2	0	0	2
Reversing/U-turn	3	0	0	3	3	0	0	3
Single accident with moped	1	0	0	1	1	0	0	1
Total	**264**	**37**	**179**	**85**	**248**	**16**	**66**	**199**

Appendix IV: Type of accidents for each intersection

No.	Intersection	Tram	Pedestrian with vehicle	Bicycle/Moped with vehicle	Crossing vehicle	Turning vehicle	Single accident with vehicle	Rear-end vehicle	Single accident with bicycle	Bicycle with bicycle	Pedestrian with bicycle	Meeting vehicle	Reversing/ U-turn	Single accident with moped	Total
1	Parkgatan/Södra vägen	0	2	1	9	2	2	5	1	0	0	0	1	0	23
2	Kungsportsavenyen/Engelbrektsgatan	1	5	2	2	0	1	1	2	1	0	0	0	0	15
3	Fridkullagatan/Liljeforsgatan	0	0	0	4	0	0	0	0	0	0	0	0	0	4
4	Skånegatan/Levgrensvägen/Bohusgatan	3	10	2	0	0	2	4	0	0	0	0	0	0	21
5	Såggatan/Amiralitetsgatan	0	0	1	0	0	0	0	1	0	0	0	0	0	2
6	Andra Långgatan/Värmlandsgatan	0	0	0	0	0	0	0	2	0	0	0	0	0	2
7	Södra vägen/Engelbrektsgatan	3	1	3	8	1	0	8	1	0	1	0	0	0	26
8	Engelbrektsgatan/Sten Sturegatan	0	3	1	0	1	1	2	0	0	0	0	0	0	8
9	Mölndalsvägen /Sankt Sigfridsgatan/Fredrikdalsgatan	0	3	4	4	0	4	11	4	0	0	1	0	0	31
10	Lorensbergsgatan/Kristinelundsgatan	0	3	0	5	0	0	0	0	0	0	0	0	0	8
11	Olivedalsgatan/Alfhemsgatan	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	Linnégatan/Nordenskiöldsgatan	3	1	0	2	0	0	0	1	0	0	0	0	0	7
13	Kustgatan/Karl Johansgatan	0	0	1	3	0	0	0	0	0	0	0	0	0	4
14	Nya Allén/Kungsportsavenyen	2	9	4	0	0	2	6	8	0	2	0	0	0	33
15	Parkgatan/Sten Sturegatan	0	3	4	0	0	7	0	0	0	0	1	1	1	17
16	Första Långgatan/Nordhemsgatan	6	0	0	2	0	0	0	0	0	0	0	0	0	8
17	Härlandavägen/Stockholmsgatan/Kålltorpsgatan	0	1	4	0	0	0	8	2	0	0	0	0	0	15
18	Delsjövägen/Töpelsgatan/Birkagatan	0	0	8	0	0	2	0	0	0	0	0	0	0	10
19	Torgny Segerstedtsgatan/Fågelvägen	9	1	1	1	2	1	4	0	0	0	0	0	0	19
20	Munkebäcksgatan/Colliandersgatan/Torpavallsgatan	0	1	1	2	1	1	3	1	0	0	0	1	0	11