



Improving traffic safety for pedestrians and cyclists at signalized intersections

A study of the traffic signal system in Gothenburg
Master's thesis in Infrastructure and Environmental Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
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MASTER'S THESIS ACEX30

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Engineering*

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Cover:

Picture of a pedestrian and a cyclist at the signalized intersection Ullevigatan-Skånegatan
in Gothenburg.

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ABSTRACT

It is more important than ever to work towards a sustainable society. The transportation sector has a big potential to contribute to a greener environment. Transport modes such as walking and cycling have been promoted as sustainable options for transportation and have become a challenge for many cities to increase their use. One of the cities is Gothenburg. Gothenburg has adopted many policies and programs to achieve a more accessible city for pedestrians and cyclists. This master's thesis studies how the current traffic system relating to traffic signals works in Gothenburg and identifies traffic safety problems for vulnerable road users at signalized intersections. The result obtained from this master's thesis shows a need for a more effective technological solution for the traffic signal system. There are some inconsistencies between the goals stated in supporting documents and implementations. The guidelines need to be clearer and more consistent to avoid conflicting interpretations. Much information is not up to date, such as information on the LHOVRA strategy. Therefore, the current documents and implementations need to be reviewed and updated regularly based on feedback and results. Additionally, this study suggests speed limit measures, clearer road markings, and leaning rails for cyclists to improve traffic safety for pedestrians and cyclists. Further research on different detection methods is recommended for continuing the work on improving traffic safety in Gothenburg.

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Gothenburg, June 2024
Abrar Daebes & Terrie Ly

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1. Introduction

Most of the world's population lives in urban areas. As urban populations grow, cities face the challenge of accommodating more residents while striving to achieve global sustainability goals. Transportation is a big part of cities' infrastructure and can therefore have a big impact on people's daily lives. Active transportation modes such as walking and cycling are necessary for health and sustainability reasons (Ullman et.al., 2022). Traffic design and built environment are two important factors to consider when promoting walking and cycling. To increase the use of active transport modes, measures to facilitate walking and cycling are needed.

Making our cities safer and easier for pedestrians and cyclists is important from a safety and societal perspective. This transition is difficult due to several factors, one of them being Sweden's infrastructure design. A new study shows that many cyclists must spend a significant portion, up to a quarter of their total travel time, waiting for green lights (Trivector, 2019). This can result in many negative effects, such as several pedestrians/cyclists having to wait for a single vehicle that extends the green period. This can cause some of them to cross at a red light due to them not wanting to wait, which is a risk to traffic safety.

One strategy for managing traffic is the use of traffic signals. The purpose of implementing traffic signals in various intersections is to allocate accessibility to different road user groups (Sektion Utformning av vägar och gator, 2004). The type of traffic signal strategy that is most used in Sweden is the LHOVRA strategy, which prioritizes motorized vehicles. Thus, the design of the traffic signal system is important to analyze and optimize to ensure accessibility for all road users. When the design of traffic signal systems does not prioritize or facilitate easy accessibility for pedestrians and cyclists it could be perceived as an obstacle for them to choose walking and cycling as transport modes. The experienced waiting time could be long and the level of service decreases. This could increase the risk of red signal violation as people want to save time and choose to ignore the signal. This dangerous behavior could lead to fatal accidents.

A safe and accessible city requires effective traffic control (Andersson et al., 2017). Traffic light signals are often the method used to manage the traffic at intersections in a city. Their purpose is to manage the traffic flows by separating the different road user groups and directing them in time via the traffic lights and prevent collisions. The majority of the signalized intersections in Sweden use the traffic signal control strategy LHOVRA. The strategy has reduced the risks of rear-end collisions and vehicles driving at red lights. It has been proven that the strategy has increased overall traffic safety at signalized intersections. However, there are still many traffic signal installations that do not use this strategy.

Gothenburg is one of the fastest growing cities in Sweden (Bibri et al., 2020). The city is also very progressive when it comes to sustainable planning and policies. They have, for example, developed The Environment and Climate Programme for the City of Gothenburg 2021-2030 (City of Gothenburg, 2021). The program is a guide for the city’s committees and boards to work towards an environmentally sustainable city. In the guide, sustainable transportation is an important part of the program, and it states that the strategy for it includes efficient mobility and priority for walking and cycling.

In Gothenburg, data from STRADA (Swedish Traffic Accident Data Acquisition) indicates a significant number of pedestrian and cyclist injuries at signalized intersections. It was reported that the period 2017-2023 (2023 not yet complete) had a total of 1515 injuries, with 165 involving traffic signals, resulting in 3 deaths and 11 severe injuries, see *Table 1* and *Table 2*. Although it is difficult to determine whether the accidents involved traffic signal violations, it is important to note that Swedish law forbids pedestrians and cyclists from crossing at red signals, which is regulated in the Road Traffic Ordinance. Still, there are no fines or legal consequences for such actions unless they result in accidents (NTF, u.d.). This could therefore influence causing accidents. Only in the event of an accident, the road user could be punished with fines, or in serious cases, imprisonment.

Table 1. STRADA statistics on accidents involving traffic signals in different locations 2017-2023 (2023 not yet complete).

| Type of location | Bicycle – vehicle | Pedestrian – vehicle | Total |
|--------------------------------|-------------------|----------------------|------------|
| Road segment | 21 | 54 | 75 |
| Intersection | 45 | 27 | 72 |
| Roundabout | 5 | | 5 |
| Bus stop | 1 | 4 | 5 |
| Traffic interchange | 1 | 2 | 3 |
| Pedestrian/bicycle lane | 3 | | 3 |
| Other location type in traffic | | 1 | 1 |
| Sidewalk | | 1 | 1 |
| Total | 75 | 89 | 165 |

Table 2. STRADA statistics on the severity of accidents between 2017-2023 (2023 not yet complete).

| Combined severity | Bicycle- Vehicle | Pedestrian-Vehicle | Total |
|-------------------|------------------|--------------------|------------|
| Fatal accident | 1 | 2 | 3 |
| Serious accident | 3 | 8 | 11 |
| Moderate accident | 8 | 20 | 28 |
| Minor accident | 64 | 59 | 124 |
| Total | 75 | 89 | 165 |

Given the increasing urban population and the demand for sustainable transportation, it is crucial to design a traffic system that prioritizes the safety of pedestrians and cyclists. This study aims to provide a deeper understanding of the traffic system in Gothenburg, focusing on the safety of these vulnerable road users at signalized intersections. By analyzing current traffic signal designs and their impact on pedestrian and cyclist behavior, this research seeks to highlight areas for improvement. Finally, the findings of this study will serve as a foundation for further research and initiatives aimed at optimizing traffic signals to enhance safety and promote active transportation modes in urban environments.

2. Literature review

This literature review is divided into five topics: Traffic safety for vulnerable road users, Traffic signal violation behavior, Traffic control systems, Gothenburg city's traffic strategy, and Accessibility in traffic. This chapter aims to describe the gap in research and motivate the need for this master's thesis.

2.1. Traffic safety for vulnerable road users

Many studies have been done to help improve safety for drivers and minimize the risk of vehicle collisions (Benamar et al., 2020). When it comes to the safety of pedestrians in traffic environments there have not been as many comprehensive studies, even though they are the major sufferers of road accidents. There is a lack of studies that focus on how to increase the safety and support for pedestrians without compromising traffic flow optimization.

Vulnerable road users (VRU), which the EU ITS directive defines as “non-motorized road users, such as pedestrians and cyclists as well as motorcyclists and persons with disabilities or reduced mobility and orientation”, are not protected in traffic as those in motorized vehicles which acts as a protective shell (Benamar et al., 2020). Thus, VRUs are more likely to sustain serious injuries and fatalities when in collision with other road users. In 2013, over 7000 pedestrians were in fatal accidents in the European Union according to the database Accidents on the Roads in Europe (CARE). Therefore, traffic safety for pedestrians is a challenge that can be tackled with ITS.

Many factors risk traffic safety for pedestrians (Benamar et al., 2020). These can be divided into four categories: Pedestrian factors (e.g., age, behaviors, impairment), Vehicle factors (e.g., design, technologies), Roadway factors (e.g., intersection design, allowed speed, signals), and Driver factors (e.g., distraction, skills, unsafe practices). The most important ones are roadway infrastructure and features, driving habits, and pedestrian factors. Many accidents happen on pedestrian crossings which can be due to the false sense of security that features and functions such as traffic signals, priority rules, and road markings can give to pedestrians (Eisses, 2011).

It is difficult to predict pedestrians' behavior which also makes it harder to model pedestrians in analyses (Benamar et al., 2020). Moreover, distractions such as taking care of children and phone usage could also impact traffic safety. This means that pedestrians could be a safety risk both for themselves as well as for other people in the traffic system because of their unpredictable behavior.

2.2. Traffic signal violation behavior

Traffic signal violation is a serious factor in road accidents (Zhang et al., 2016). The risk of injuries is higher when traffic signal violation is involved when compared to other types of accidents. Previous studies have shown that pedestrians' signal violation behavior is affected by both social and non-social factors. Demographic factors have been shown to play an important role when it comes to signal violation behavior (Mukherjee & Mitra, 2020). For example, young adults and male pedestrians are those who have a higher tendency to violate traffic signals. It is also found that the use of electronic devices increases red signal violation. The risk of pedestrians crossing at a red signal is influenced by waiting time, crossing speed, and the cycle length of the traffic signal system (Raoniar & Maurya, 2022). Other factors include number of people waiting and the group effect. The risk of red-light violation increases when the number of people waiting is fewer and/or if other people cross the road during the red signal. People get impatient when they experience the waiting time to be long. Signal design and planning is therefore an important aspect to consider, to lower the risk of signal violation and thus increase traffic safety.

Engineering factors which include traffic signals, road design, and refuge islands can also influence pedestrians' behavior (Zhang et al., 2016). Research has shown that traffic signals and other road signs highly affect how people act in traffic. For example, people are more observant when crossing at crosswalks with no road markings.

The environment also plays a part in people's behavior (Zhang et al., 2016). Weather conditions and time of day are some examples. Cyclists tend to commit traffic violations when in sunny and warm weather conditions (Zhang & Wu, 2012). Previous studies have shown that installing sunshields minimizes the risk of cyclists running red light. Another study presented that more than half of the pedestrian accidents happened during nighttime (Zhang et al., 2016). There is also a higher percentage of pedestrians going against the red signal on weekends and holidays. Other studies have also found that how developed a country is influences how well people follow regulations. People in developed countries are more likely to follow traffic regulations than people in developing countries. When it comes to traffic accidents, the injury rate is lower in developed countries compared to developing countries.

2.3. Traffic control systems

Group-based traffic control is a popular strategy that has been implemented all around the world (Jin & Ma, 2014). Its popularity has grown in the past years as previous studies have shown that this type of traffic control is overall better than stage-based control. This type of traffic control is more flexible and minimizes unused green time. However, it is more difficult to evaluate signal controllers in practice than in simulation-based studies and there is potential to optimize group-based controllers (Grumert & Pereira, 2021; Jin & Ma, 2014).

One of the group-based traffic controls is the LHOVRA control which is commonly used in the Scandinavian countries. LHOVRA includes different functions that allow the flexibility to assign different variable signals (Archer, 2005). The name LHOVRA stands for the different functions in Swedish, which translated to English are L=Heavy Goods Vehicle/Bus, H=Major Road priority, O=Incident reduction, V=Variable Yellow, Red-Light Violation Control, and A= All red turnaround. The strategy intends to optimize accessibility for motorized vehicles, which makes pedestrians and cyclists not a prioritized road user group when implementing this strategy.

The L function is meant to give priority to certain traffic flows at intersections, especially heavy traffic such as trucks (Sektion Utformning av vägar och gator, 2004). This function is designed to reduce waiting times and unnecessary stops for heavier vehicles and buses by changing the signal's green time on their commonly used routes. This improves the traffic flow and safety at signalized intersections. The LHOVRA system's H function is designed to prioritize main roads at signalized intersections by optimizing the green light sequences so that traffic moves more smoothly and quickly, which reduces congestion. This kind of strategic planning is important in cities where main roads carry more traffic. Incident reduction, the O function, works by prolonging the length of green time when drivers are in the "decision zone". This refers to the part where drivers must decide whether to stop or keep driving when the light turns yellow. Extending the green time, allows them to safely pass the crossing before the light turns yellow, thus lowering the number of accidents.

By reducing unnecessary delays during the yellow light phase, when there is no incoming traffic, the V function aims to minimize the waiting time at intersections (Sektion Utformning av vägar och gator, 2004). When the signal is ready to turn yellow with no cars approaching from a suitable distance, the yellow phase will be shortened. The purpose of the R function is to improve and regulate vehicle behavior to avoid red-light running. This will increase traffic safety by detecting cars that attempt to run a red light and changing the traffic signal cycles accordingly. The LHOVRA system's A function involves a brief period where every traffic signal at a signalized intersection is red. This is aimed at emptying the intersection of all road users before a new green phase begins for any direction, thus enhancing safety and traffic flow efficiency.

In Sweden and other Scandinavian countries, the technique has been broadly used in both rural and urban areas, with great success (Engstrom, 1994). The article "10 Years with LHOVRA-What are the experiences?" provides an analysis of the effectiveness of

LHOVRA technology and its socioeconomic impact. Research indicates that the application of the technique has resulted in a lower rate of traffic accidents by approximately 25% in areas with a speed limit of 50 km/h and 70 km/h. When compared to conventional approaches, the O-function significantly increases traffic safety, according to socioeconomic analysis. Another article that also mentions the effectiveness of the O-function is “Implementation and Optimization of Group-based Signal Control in Traffic Simulation”. It emphasizes how it helps make traffic safer by prolonging green time with advanced detection technologies (Jin & Ma, 2014). SUMO (Simulation of Urban Mobility), a traffic simulation tool, was used to establish that extending green duration reduces the risks of “decision zones”.

2.4. Gothenburg city’s traffic strategy

The LHOVRA strategy is used in most cases in Sweden (Grumert & Pereira, 2021). Sweden’s second-largest city Gothenburg is an interesting city to investigate in regard to the traffic system. Gothenburg’s identity and infrastructure have often been characterized by the car industry (Knutsson & Hellberg, 2023). In recent years the city of Gothenburg has developed policies and goals to tackle climate change and lower carbon dioxide emissions. The focus is on reducing car traffic, improving public transportation, cycling, and walking. The city has, for example, adopted a congestion charge system and invested in walking and cycling paths (Pettersson et al., 2021).

The Future Today Institute ranked Gothenburg as number two among the world's smart cities, in 2019 (Pettersson et al., 2021). One of the criteria was public transport and ride-sharing services. Gothenburg is also one of the cities that is top of the list when it comes to sustainable transport policy and planning. Gothenburg city planners have since the 1950s planned toward a more accessible city with public transport, walking, and cycling. However, there could be a difference between the introduced policies and plans, and what is implemented.

2.5. Accessibility in traffic

The challenges that the world faces such as growing population and environmental issues, bring the need for sustainable solutions in the transport system (Lättman et al., 2018). It has become more and more important to work towards a transport system that focuses on sustainable transport modes, such as public transportation and cycling, rather than car use. To promote these sustainable transport modes, it is essential to ensure that they provide sufficient accessibility in traffic. In many European transport policies, one of the most important goals is to have accessibility for everyone. Accessibility in a city is a prerequisite for an including society and better public health (Vlug et al., 2022). Accessibility in traffic has most often been measured with travel times and travel distances. However, these are only a few of the factors that affect accessibility.

Two types of accessibility are important to consider when planning accessibility, objective accessibility, and perceptions of accessibility (Vlug et al., 2022). Often the most common measures of accessibility do not take peoples' perception of accessibility into account and only consider objective accessibility. Objective accessibility considers factors such as attributes of transport modes, costs, and distances and does not consider different groups of individuals and differences in accessibility within a geographical area (Lättman et al., 2018). Perceived accessibility is how people experience the conditions that they live in. People may have different opinions on accessibility because of their personal preferences.

Not taking perceived accessibility into account when studying accessibility would result in inaccurate evaluations and measurements of accessibility (Jamei et al., 2022). It is essential to include the accessibility perceptions of different groups when evaluating and planning traffic accessibility (Lättman et al., 2018). Studies show that people walk more if the perceived walking accessibility is higher (Vlug et al., 2022). The perceived accessibility can be changed due to several factors, including safety and a barrier-free environment. Hence, the importance of enhancing the perception of accessibility to promote walking.

2.6. Motivation for the study

To encourage people to choose walking and cycling, peoples' perceived accessibility needs to be considered when planning mobility. Signalized intersections could be seen as a barrier due to perceived waiting time. Long waiting times can cause people to cross the road at the red light and lower traffic safety. Thus, a study about pedestrians and cyclists at signalized intersections and their perceived accessibility is of interest.

Gothenburg city's advocacy for cycling and walking as preferred transport modes in Gothenburg, along with the use of the LHOVRA strategy, makes it essential to study how the traffic system in Gothenburg operates and how it considers vulnerable road users' safety while promoting sustainable transport modes. This thesis seeks to provide a clear understanding of how the traffic signal system in Gothenburg works and identify the problems relating to traffic safety for pedestrians and cyclists in signalized intersections.

Despite the emphasis on improving vehicle safety, there is a notable lack of comprehensive studies focused on enhancing pedestrian and cyclist safety without compromising traffic flow. Additionally, while traffic signal violations are a significant cause of accidents, there is limited research on the specific factors leading to these violations by pedestrians and cyclists. Understanding these behaviors is crucial for proposing effective measures to reduce violations and improve safety at intersections.

Furthermore, although the LHOVRA strategy optimized traffic flow for motorized vehicles, its impact on vulnerable road users has not been thoroughly reviewed. This study will explore how well the system accommodates pedestrians and cyclists and suggest necessary improvements. By conducting interviews with experts, analyzing technical documents, and performing a case study at a signalized intersection, the study will gather data on current practices and the challenges faced by vulnerable road users.

Finally, most research on traffic accessibility relies on objective measures, often overlooking perceived accessibility. This study aims to integrate perceived accessibility into traffic planning by evaluating how pedestrians and cyclists perceive their ease of movement and safety at intersections. Through interviews and observational studies, the research will identify key factors influencing perceived accessibility and recommend strategies to address these concerns. This comprehensive approach will help create a more inclusive and user-friendly traffic environment in Gothenburg.

By addressing these gaps, this research will contribute to the development of a safer and more accessible traffic system in Gothenburg, promoting sustainable transport modes and ensuring the safety of all road users.

3. Aim and objectives

The purpose of this master's thesis is to investigate how the current traffic system relating to traffic signals in Gothenburg, Sweden, manages pedestrian and cyclist traffic at signalized intersections. This thesis will identify the problems with the current traffic system. This thesis aims to get a better understanding of the system and will provide a basis for how traffic control can be optimized to increase accessibility for pedestrians and cyclists, which will lead to better traffic safety.

- Provide a comprehensive review of how the traffic system at signalized intersections works in Gothenburg.
- Identify the problems with the current traffic signal system regarding traffic safety for pedestrians and cyclists.
- Analyze the traffic safety for cyclists and pedestrians in Gothenburg.
- Investigate differences in provided guidelines and documents and actual implementations.

4. Method

The methods to research this topic include technical review, interviews, and a case study. In addition, a comparative analysis of documents and what is implemented were made.

Technical review

The technical review is based on an assessment of Gothenburg's traffic safety and traffic signals through an analysis of a variety of supporting documents. This involved providing an overview of the regulations in the documents regarding intersection and traffic signal design, as well as traffic safety. The review is used to summarize and compare these papers to find out how well the guidelines are aligned with how they are used in the city. The aim was to provide a thorough analysis of the current strategy for traffic safety in the city of Gothenburg. Most of the documents were suggested by the interviewees who were consulted during the research process. Their advice was used to choose the most relevant and authoritative documents that guide traffic safety and signal management in Gothenburg.

Interviews

This study has been conducted using information from qualitative interviews with experts in traffic signals, traffic systems, and traffic safety. The questions asked were constructed to get a broad understanding of the current traffic system. An understanding of the current traffic safety in signalized intersections was an important first step to identifying the extent of the problem. This was obtained by interviewing people who work with traffic planning and safety. The safety questions were as follows:

- How is the safety generally at signalized intersections in Gothenburg today?
- In terms of traffic safety, what kind of problems are there in signalized intersections?
- What type of signalized intersection has the most accidents occurred? Is it because cyclists and pedestrians cross at a red light?
- What is needed to increase safety for pedestrians and cyclists?

The next step was to get an understanding of how the traffic signals in intersections work in Gothenburg. To get this information both interviews and literature studies were conducted. The guide VGU (Vägar och gators utformning) of The Swedish Transport Administration, the technical handbook of the City of Gothenburg, and other documents relating to traffic signals and systems were studied. Several people working with traffic signals were interviewed with the following questions:

- How are traffic signals designed in intersections?
- Are the traffic signals time or traffic-dependent?
- What type of detectors are used?

- Does the traffic signal system consider traffic safety for pedestrians and cyclists? If so, how?
- Are there any plans to change the current system? Or implementing other detection systems?

Case study – Ullevigatan-Skånegatan

To further understand traffic safety for pedestrians and cyclists, a case study was conducted at one of the most problematic intersections in Gothenburg regarding reported complaints, according to the City of Gothenburg. The intersection that was studied was Ullevigatan-Skånegatan, in central Gothenburg. This intersection was chosen due to its complexity. The pedestrian and cyclist path intersects with roads for motorized vehicles, buses, and trams. The surrounding area of the intersection is a busy area with offices, restaurants, schools, and residential buildings nearby.

Pedestrians were asked safety-related questions:

- How safe do you feel crossing this intersection?
- Do you experience the waiting time to be long?
- What are your thoughts on this intersection regarding safety?
- Do you think there is enough time to cross the intersection safely?
- Are there any features of the intersection that make you feel safe or less safe?
- Have you chosen another route to avoid this intersection? If yes, why?

Due to the difficulty of stopping cyclists in a busy intersection without disturbing other cyclists, cyclists were excluded from the interviews.

The questions were designed to obtain short answers to increase the chance of people willing to be interviewed. The interviews aim to give an understanding of the perceived safety for pedestrians and the extent of safety problems at the intersection.

There were also observations made on the intersection. The observations include:

- The design of the crosswalk.
- Green time and waiting time.
- How often do people need to stay on the refuge island.
- How often do people cross at a red signal.

Comparative analysis

To investigate whether there are differences between handbooks and guidelines, and what is implemented, comparisons between interview answers and different documents were made. Interviews were also compared to find similarities and contradictions in the answers from different experts. The following key points were considered when doing the comparisons:

- Prioritized road user group.
- Problems with the current traffic system.
- How safety for pedestrians and cyclists is considered in the design of signalized intersections.

5. Current situation in Gothenburg

Through governing documents, city officials can specify how they plan to carry out political objectives. These objectives are based on legislation, political will, and feedback from citizens, consumers, and clients. This chapter focuses on the recommendations in some of these documents concerning traffic signals, traffic safety, and intersections. These regulations provide detailed guidelines that assist planners and local authorities in creating safer and more efficient traffic systems. The city hopes to decrease accidents, promote traffic flow, and improve everyone’s safety on the roads. Figure 1 illustrates different supporting documents regarding traffic signals and traffic safety divided into four categories: Global, National, Regional, and Local.

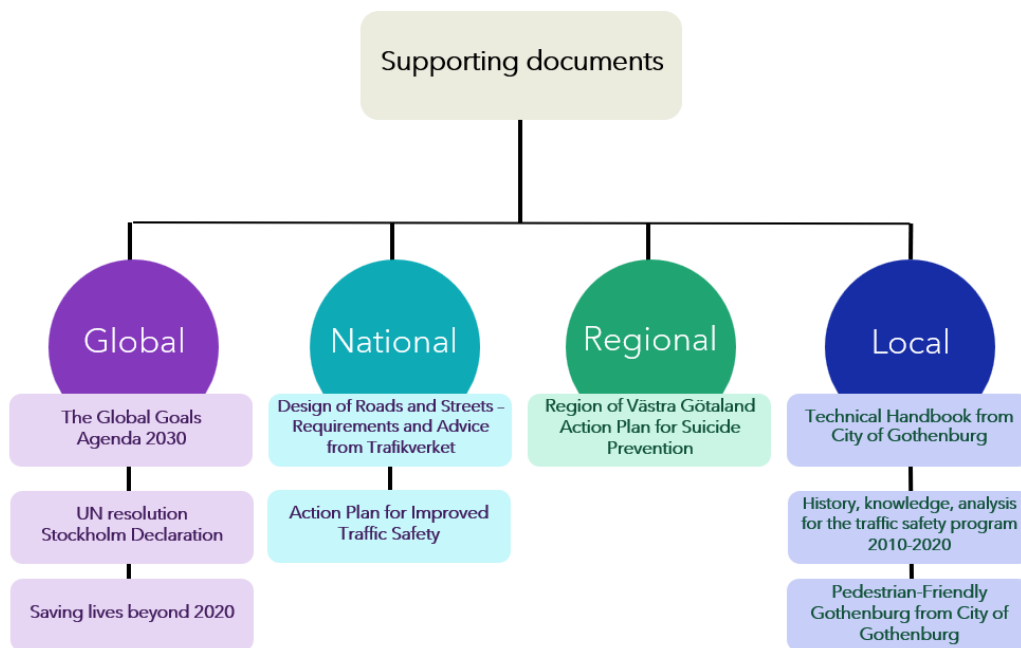


Figure 1. Overview of supporting documents on different levels.

The supporting documents cited in the technical review are shown in the following table, see *Table 3*. The interviews with a variety of specialists who are actively involved in traffic management within the City of Gothenburg led to the identification and recommendation of these documents. The interviewees have firsthand experience and expertise in the field, which ensured that the documents were relevant and authoritative. These papers, which address the challenges that the city’s traffic system encounters, are not only solid in theory but also practically useful.

Table 3. Supporting documents cited in the technical review.

| Supporting document | Issued (Year) | Organization | Purpose |
|--|---------------|--|--|
| Drive When it's Green | 2017 | The Swedish Association of Local Authorities and Regions | The document aims to educate and assist traffic control specialists, especially newcomers, on how to design and maintain traffic signals to ensure safety and efficiency for all road users. |
| Design of Roads and Streets | 2004 | Transport Agency's Regulations | The document's objective is to offer recommendations to road authorities and traffic signal designers when they plan traffic signal systems for state and municipal roads. |
| Technical Handbook | 2023 | The City of Gothenburg | The Technical Handbook provides guidance and standards for planning, designing, building, and maintaining infrastructure in Gothenburg. It serves as a comprehensive reference for engineers, planners, and contractors working on municipal projects. |
| Transport Agency's Regulations and General Advice on Traffic Signals | 2014 | Transport Agency | The document's goal is to establish regulations and general guidelines for traffic signals in accordance with the Road Signs Ordinance (2007:90). |

| | | | |
|--|------|---------------------------|---|
| Pedestrian-friendly Gothenburg | 2019 | The City of Gothenburg | The document complements other city guidelines, intended for traffic office employees and urban development workers, with the goal of improving the walking environment and understanding pedestrian needs. |
| The Traffic Committee’s Traffic Safety Plan for 2023-2024 | 2022 | The City of Gothenburg | The aim of the document is to establish goals and standards to reduce traffic fatalities and serious injuries in Gothenburg. |

5.1. Designing traffic signals according to supporting documents

Traffic signals are mentioned in various documents, outlining rules and guidelines for their use, installation, and maintenance. This subchapter summarizes the supporting documents regarding designing traffic signals.

5.1.1. Drive When it’s Green

The Swedish Association of Local Authorities and Regions has published a document about designing traffic signals. “Drive When it’s Green” from 2017 mainly describes how traffic signals should be designed in accordance with the regulations and how to create an effective and safe traffic environment for all road users (Andersson et al., 2017). It emphasizes that traffic signals are essential in order to manage traffic flows and establish safe and functioning intersections. In addition to directing traffic and managing capacity in urban areas with high traffic demand, traffic signals also serve as safety features in high-speed and intersecting traffic areas.

The document mentions signalized intersections and the different duration times for each signal. The time for green and flashing green signals must be long enough for a pedestrian who starts crossing when the signal turns green to fully cross the road before the signal turns red (Andersson et al., 2017). This time is calculated based on a walking speed of no more

than 1.4 m/s, and the flashing green signal must be displayed for at least five seconds. Since it is believed that cyclists can stop faster than cars, a bicycle signal's yellow time should be three seconds. In contrast, a vehicle's signal takes four seconds. Regarding the green signal period for cyclists, it should be adjusted according to the distance the cyclist travels. However, it must be at least five seconds to ensure that they can fully cross before the signal changes to yellow.

Also mentioned is that bicycle signals should be placed on the right side to avoid misunderstandings and ensure cyclists follow the right-hand traffic (Andersson et al., 2017). Regarding the proper placement of traffic signals and poles, it is vital to ensure they are visible to all road users and do not pose a risk. Maintenance workers should be able to safely do their jobs and they should be placed where users expect them. By keeping enough room between signal poles, snow can be cleared more easily, and maintenance workers do not have to worry about knocking over signals.

5.1.2. Design of Roads and Streets

“Design of Roads and Streets” is a document that was developed by The Swedish Transport Administration. The purpose of this document is to describe the requirements and regulations for designing roads and streets (Sektion Utformning av vägar och gator, 2004). It is meant to be used by The Swedish Transport Administration while it is an advisory guide for municipalities in Sweden. It consists of two documents, one about the design process and another one as a supporting handbook. People who use it include everyone who works with designing a road or a street, such as traffic planners and project leaders.

The traffic signal control technology is built on many functions and variables (Sektion Utformning av vägar och gator, 2004). These factors can vary for each traffic signal installation. Moreover, a traffic signal installation can be controlled together or separately from other signal installations. There are different types of traffic signals depending on which factor is considered. The most conventional is the fixed-time traffic signals that are programmed to set time intervals. This can either be a fixed time for a whole day or different intervals depending on the time of day. If the traffic signal is based on the traffic flow, then it is considered an actuated traffic signal.

There are two common control methods (Sektion Utformning av vägar och gator, 2004). These include traffic traffic-dependent method and the time-controlled method. The traffic-dependent method uses different detection methods, such as vehicle detectors or push-button detectors, to control the traffic signals. The time-controlled method uses fixed times to manage the traffic.

Traffic signals are often regulated in schedules (Sektion Utformning av vägar och gator, 2004). These schedules describe the current traffic situation. The schedules are affected by, for example, rush hours, accidents, and other events that affect the traffic. It is difficult to

determine strategic locations for measuring and identifying the current traffic situation. Another challenge is to get accurate reports about changes in traffic fast. Very short traffic changes mustn't be affecting the schedules. It is also important to not have too many schedules. Too many schedules would make the system ineffective and cause traffic disturbances.

How the traffic signal installations are designed and cooperate can affect nearby traffic (Sektion Utformning av vägar och gator, 2004). To have a better overview of these traffic signal installations and know how to manage them, the larger area can be divided into signal areas. The signal area could cover a few nearby intersections or an area with connected traffic.

5.1.3. Technical Handbook from the City of Gothenburg

A technical handbook was released by the Urban Environment Department to guide contractors, consultants, and other stakeholders involved in the planning and design of public areas (Göteborgs Stad, 2024f). Twice a year, at the end of April and October, the Handbook is updated. The guidelines and requirements should be followed and can only be deviated from by the approval of the Urban Environment Department.

In one of the chapters, it is mentioned that signalized intersections should not be regarded as a safety measure and should prioritize public transportation and emergency vehicles (Göteborgs Stad, 2023d). Also mentioned is that cyclists and pedestrians should be able to get green time either simultaneously with or ahead of parallel vehicles. Variable message signs, such as a bicycle symbol, can be used as a way of informing the drivers that the bike has a green light parallel to turning vehicles. If needed, radars should be used to extend the green time for pedestrians.

Bicycle and traffic signals

According to the technical handbook, the traffic signal for cyclists should have constant notification if possible. If not, the handbook describes several rules about the detection system for cyclists, such as the installation of push-button detectors. The following are the rules described in the handbook:

- Push button boxes should be installed on a console so that the front wheel of the bicycle does not reach the roadway. The console should also not protrude over to the bike lane.
- The push button should be on the right-hand side and easy to access without having to step off the bicycle.
- The push button box should be yellow and have an indicator light that is visible at least 270 degrees around the box.
- If possible, there should be an automatic detection with detector loops or radar.
- The push button box should be installed even if there is automatic detection.

- There should be over-registration and prolongment of green time from parallel signals around the clock.
- Over-registration from public transport is done in some cases.
- Bicycle detector loops should be placed 20-40 meters from the stop line on the plane surface. The speed determines the distance. Double detection points at different distances can be used to ensure accurate detection. The detection loops can be installed in pairs to determine the direction of the bicycle.

Pedestrians and traffic signals

The placement of traffic signals for pedestrians should be in line so that there is minimal risk for pedestrians to look at the wrong traffic signal (Göteborgs Stad, 2024a). When trams or bus lanes are involved, double traffic signals and electronic bells should be installed. The traffic signals should have the green signal covered so that only red signals can be turned on. The reason behind covering the green signal is to make sure that pedestrians do not mistake traffic signals. Green time can be prolonged with radar detection in cases such as if there are schools and retirement homes nearby.

The push button box should be blue, as opposed to the yellow push button boxes for cyclists (Göteborgs Stad, 2024a). The indicator light should be visible at least 270 around the box. There should also be a directional arrow on the box.

Vehicle detection in traffic signals

Different detecting systems and installation techniques are used, depending on the kind of vehicle, traffic composition, and material of the street (Göteborgs Stad, 2023a). To give public transportation priority over other traffic at signal-regulated crossings, a patented detecting system called SignalPrio is used by the Urban Environment Department. Determining the position of the vehicle is an essential requirement to prioritize.

In addition, inductive loop detection is used as well. Trams use RFID tags positioned on the ground along with GPS technology (Göteborgs Stad, 2023a). Buses and other non-tram vehicles use GPS technology. An alternative method that can be used is an inductive loop when trams run on their track or lane, see *Figure 2*.



*Figure 2. Installation of detector loop for trams on wooden frame including junction box (Göteborgs Stad, 2023)
(Photo: Andreas Larsson).*

Since inductive detection provides a more accurate detection, it is frequently used for vehicles and bicycles (Göteborgs Stad, 2023a). Radars and other surface detection methods can be useful in certain situations.

5.1.4. Transport Agency’s Regulations and General Advice on Traffic Signals

The 2014 document “Transport Agency’s Regulations and General Advice on Traffic Signals” aims to establish traffic signal regulations in accordance with the Road Signs Ordinance (2007:90) (Transportstyrelsen, 2014). The Swedish regulation defines the requirements for road signs and traffic signals, including their design, placement, and maintenance to enable safe traffic management (Sveriges Riksdag, 2007). The document contains details rules for the placement, quantity, and size of traffic signals, as well as where they should be placed so that motorists can see them clearly.

There are also recommendations for positioning and designing bicycle and pedestrian lights (Transportstyrelsen, 2014). One of the chapters discusses how long different signals should be displayed to ensure enough time for vehicles, cyclists, and pedestrians to safely pass through intersections. Red and yellow signal is a combination used in vehicle and bicycle signals and should be displayed for 1.5 seconds. If the signal regulates traffic on an access

road only, this time can be reduced to one second. For vehicle signals, the yellow signal should be displayed for 4 seconds where the maximum speed limit is below 60 km/h. In bicycle signals, the yellow signal should be displayed for 3 seconds. Green signals should be displayed for a minimum of 4 seconds for vehicles and 5 seconds for bicycle signals. If the signal only regulates traffic on an access road, this time can be reduced to one second. In pedestrian signals, the total duration of the green and flashing green signals should be long enough for a pedestrian moving at a maximum of 1.4 m/s to cross before turning red.

5.2. Traffic safety in supporting documents

The municipality of Gothenburg has a vision to increase traffic safety in the city. Vision Zero is the basis of Gothenburg's dedication to this vision and has been the driving force behind methodical attempts to lower accident rates (Göteborgs Stad, 2023b). Vision Zero is a multi-national goal based on the idea that accidents should not be considered the mistake of road users since all humans make mistakes (Government Offices of Sweden, 2019). Instead, the focus should be on creating safer and optimized transport systems to prevent fatal accidents. Other bases for this are The Global Goals and the 2023 Agenda for Sustainable Development with a focus on targets 3.6, 11.2, 12.6, 12.7, and 8.8 (Göteborgs Stad, 2022). The first two guidelines are specifically aimed at increasing traffic safety. Target 3.6 states that global deaths and injuries from traffic accidents should be halved by 2030 (Globala målen, 2022). Target 11.2 is set to make sustainable transportation systems available for all (Trafikverket, 2023).

On May 1, 2000, Sweden implemented the Zebra Crossing Law. According to the legislation, a motorist is required to yield to pedestrians who have entered or are about to enter an unsupervised pedestrian crossing with no traffic signals. The law was intended to improve pedestrian safety and simplify pedestrian crossing laws in Sweden to align with international standards observed in several other countries (Torstensson, 2008).

5.2.1. Technical Handbook from the City of Gothenburg

To increase traffic safety, the main emphasis should be on managing vehicle speed, which has a substantial impact on the severity of accidents (Göteborgs stad, 2023b). Improvements to the infrastructure design are made with a particular focus on vulnerable groups such as pedestrians and cyclists. Despite urban growth, the goal remains to focus on traffic safety and integrate it into all aspects of urban projects. This includes all new construction and renovation projects, as well as maintenance and operational work. The traffic safety chapter in the "Technical Handbook" is simplified and it refers to the document "The Traffic Committee's Traffic Safety Plan for 2023-2024" for a detailed description of how to work with traffic safety.

5.2.2. Pedestrian-friendly Gothenburg from the City of Gothenburg

Increased mobility in cities has several benefits for people and society as a whole (Göteborgs Stad , 2019). The purpose of this document is to raise knowledge of pedestrians and the fundamental ideas that can support Gothenburg’s city planning initiatives to encourage walking. It began as a political command to draft a new Gothenburg City regulation, and it resulted from joint work by the departments of traffic, park and nature management, urban planning, and property management. The goal of Gothenburg City, which is to become a close-knit, green, and cohesive city with 150,000 new residents by 2035, has a significant impact on how the city should operate and be experienced on foot. Pedestrians have always played a major role in the development of cities and have historically been the main driver of urban expansion. Urban planning and research both emphasize how important walkability is to create livable, sustainable communities.

5.2.3. Traffic Committee’s Traffic Safety Plan for 2023-2024

“The Traffic Committee’s Traffic Safety Plan for 2023-2024” is a strategic document, from the City of Gothenburg, aimed at guiding and directing traffic safety work within areas such as new construction, redevelopment, urban development, and maintenance (Göteborgs Stad, 2022). It also focuses on communication, behavioral influence, research, and innovation to reduce traffic-related deaths and serious injuries. The plan specifically emphasizes improving traffic safety by prioritizing pedestrian and cyclist safety in urban areas. It outlines the goal of making streets safer for pedestrians by making sidewalks more slip-resistant and even, especially during winter months, to prevent fall-related accidents. Furthermore, constructing well-connected and well-maintained cycling infrastructure and pedestrian pathways is mentioned as a way of enhancing their safety and creating a safer and more attractive environment for all road users.

5.3. Design of signalized intersections in supporting documents

In the technical handbook it states that to promote a smooth interaction between pedestrians, cyclists, and vehicles, intersection designs should focus on drawing the driver’s attention while reducing speed (Göteborgs Stad, 2023d). The choice of intersection type should be made considering various factors such as traffic engineering requirements, traffic flow, accessibility, safety, environmental impact, construction, operation, and maintenance costs, as well as design. The document provides recommendations for intersection design that prioritizes safety and efficiency for all road users (Göteborgs Stad, 2024d). To improve safety, refuge islands should be utilized as a safe waiting space when users are unable to cross the entire road during one green signal period (Göteborgs Stad, 2024b).

The section “3GH Waiting areas for pedestrians and cyclists”, states that pedestrians and cyclists should be able to cross the intersection without having to stop in the middle (Göteborgs stad, 2024c). However, there should still be a refuge island in case some people

cannot cross the intersection in time. Depending on the complexity of the intersection, the need for waiting areas should be investigated. For example, waiting areas for cyclists could be needed. According to the handbook, the waiting areas should meet certain criteria. The waiting area measurements should ensure room for strollers, wheelchairs, etc. The dimensions should also account for future traffic flows and be based on the hour with the maximum traffic flow. Waiting areas for bicycles can be divided into parts in case of lack of space.

The handbook also states that leaning rails for cyclists can be installed to increase comfort for cyclists (Göteborgs stad, 2024c). The leaning rails can be installed if it is suitable for the area and does not constitute an obstacle. The leaning rails should be around 1200 mm and the footrest should be around 200 mm above ground.

5.4. Analysis of the supporting documents

The supporting documents reviewed in this chapter emphasize creating a safe and efficient traffic environment for all road users. For instance, documents like “Drive When it’s Green”, “Technical Handbook”, and the “Traffic Committee’s Traffic Safety Plan” highlight the importance of designing traffic signals to manage traffic flows and establish safe intersections. These documents consistently prioritize the safety of pedestrians and cyclists, recommending adequate green times and safe crossing areas. For example, the “Technical Handbook” suggests using variable message signs and radar detection to extend green times for pedestrians and cyclists, ensuring their safety at intersections. Moreover, there is agreement on the proper design and placement of traffic signals to ensure visibility and safety.

However, there are notable conflicts and gaps in the documents. One significant conflict arises between the LHOVRA strategy, which primarily optimizes traffic flow for vehicles, and the emphasis in other documents on prioritizing vulnerable road users. The LHOVRA system focuses on reducing delays for heavy vehicles and prioritizing main roads, potentially compromising the safety and convenience of pedestrians and cyclists. Another conflict lies in the allocation of green time. While “Drive When it’s Green” and the “Technical Handbook” recommend specific green times to ensure safe crossings for pedestrians and cyclists, the “Design of Roads and Streets” document mentions fixed-time and traffic-dependent methods for traffic signal control, which might not always align with the need for adaptive green times for vulnerable road users.

There are also significant gaps in the current research and guidelines. Comprehensive studies focused on enhancing pedestrian and cyclist safety without compromising traffic flow are lacking. The documents do not provide detailed strategies for balancing the safety of vulnerable road users with the optimization of traffic flow for vehicles. Additionally, while the documents acknowledge the importance of signal design in reducing traffic signal

violations, there is limited information on how to reduce these violations by pedestrians and cyclists.

Another gap is the focus on objective measures of accessibility, such as travel times and distances, often overlooking perceived accessibility. The documents do not sufficiently address how pedestrians and cyclists perceive their ease of movement and safety at intersections, which is essential for creating a more inclusive and user-friendly traffic environment. Lastly, while the "Technical Handbook" mentions the use of radar and automatic detection systems, there is a gap in the practical implementation and effectiveness of these technologies. More research and pilot projects are needed to assess how well these advanced detection systems can improve the safety and efficiency of signalized intersections for vulnerable road users.

Addressing these inconsistencies, conflicts, and gaps will contribute to developing a safer and more accessible traffic system in Gothenburg, promoting sustainable transport modes, and ensuring the safety of all road users.

6. Applications in practice

The interviews conducted in the research are summarized in this chapter. Insightful opinions and viewpoints regarding traffic signals and traffic safety from important stakeholders and experts in the field were obtained. This chapter seeks to provide a practical perspective of their opinions.

6.1. Gothenburg City's use of supporting documents and guidelines

The Technical Handbook is the governing document in the City of Gothenburg which outlines how things should be built, managed, designed, programmed, etc. As it addresses many of the aspects that must be taken into consideration, it serves as a reference for city planners. This is then combined with other regulatory documents like the Transport Agency's Regulations and The Swedish Transport Administration's document "Design of Roads and Streets". Transport Agency's Regulations is used specifically for the technical aspects of traffic signals, while Design of Roads and Streets is mainly used for the design of intersections. The Urban Environment Department is the content coordinator of Gothenburg City's "Technical Handbook", which is updated twice a year, rephrasing texts, and making improvements based on the planner's own experiences.

6.2. Traffic safety at signalized intersection

In Gothenburg, traffic safety is increased by reducing speed rather than relying on traffic signals. While signals are crucial for accessibility, the city focuses on measures like speed limits to create safer streets for pedestrians and cyclists. Severe accidents are more common, in particular at multi-lane crossings. Bicyclists who run red lights are one of the problems. To decrease the overall speed, authorities are taking a cautious approach and emphasizing the installation of additional speed deterrents. Also, it is not possible to have speed signs everywhere in densely populated areas since the basic speed limit applies. Drivers are expected to maintain 50 km/h in these zones.

Long bicycle passages can be challenging because many cyclists tend to rely on their judgment and ignore red traffic signals. Many bikers are unwilling to stop and would rather cross the passage before the signal turns red. This behavior raises questions about safety since many choose to continue their journey, increasing the risk of accidents. As a solution, extending the green time could decrease the risk of accidents and better traffic safety. If cyclists need to make a stop, larger waiting zones called refuge islands can be an alternative to a safe waiting area. This could also be safer for those who may be slower than others, such as elders, people with disabilities, and children.

Traffic signals are most often not preferred as a safety measure. Instead, traffic design that includes speed reduction is more optimal. These include constructing speed bumps, and

roundabouts and reducing the maximum speed. Another measure is to separate different traffic groups. Traffic signals would not be needed if the maximum speed were to be reduced to 30 km/h. However, this would make the traffic flow slow and ineffective and does not work in larger cities as traffic signals are needed to stop pedestrians.

One of the main challenges in the city is red light running, especially among cyclists. According to the City of Gothenburg, eight times out of ten collisions between vehicle and bicycle, the cyclists are at fault. Since 2017, the Urban Environment Department in Gothenburg has been attempting to increase traffic safety for cyclists by installing sensors instead of the conventional push-button. There are no statistics on the number of detectors, but they should be installed in intersections when possible. This is to promote a better flow and prevent the cyclists from having to stop.

An example of this is a sensor that was installed at the Ullevigatan-Skånegatan intersection in Gothenburg, see *Figure 3*. In larger intersections, turning cars have a lot to consider, such as parallel cyclists and pedestrians who also have green lights at the same time. It may be challenging for a driver to notice cyclists approaching at a fast speed if they are only paying attention to oncoming traffic. After complaints from both drivers and cyclists, as well as incidents at the intersection, it was decided to address this issue by putting up a sign warning turning vehicles of cyclists.



Figure 3. Warning for cyclists signs

6.3. Traffic signals

Since the 1980s, the traffic signal control strategy called LHOVRA has been used in Sweden. The system has not been updated since it was introduced and is therefore the same now as it was forty years ago. LHOVRA does not consider how many people are waiting in an intersection. The green time for motorized vehicles is prolonged when the system detects them, which means longer waiting time for pedestrians and cyclists. This could lead to an increasing number of people congregating on the sidewalks, waiting for the green light. For example, ten years ago, a traffic planner may have prioritized vehicles by establishing a green wave which shows less consideration for pedestrians and cyclists as well as longer waiting times. Today, however, there are different priorities so that is something to reconsider.

According to the Urban Environment Department, the LHOVRA strategy is used in Gothenburg but not all functions in LHOVRA are used in urban areas. Although the system is old, the Urban Environment Department states that it has been developed in how to prioritize and optimize signalized intersections for different road users. However, it is agreed that the system has optimization potential especially when it comes to detectors above ground.

Installing traffic signals at an intersection is not enough to increase traffic safety. Speeding can still lead to more accidents. Therefore, roundabouts were considered safer and started to be constructed instead of intersections in the 1980s as a way of increasing safety. Signalized intersections are more practical near the city center, whereas roundabouts are typically constructed outside of it. The main reason is to prioritize public transport since sustainability is a high priority, especially in the crowded city center. Traffic signals are important to be able to prioritize which road use that will be granted green time. This is especially of importance in Gothenburg since the trams hold the highest priority in traffic and should always be granted immediate green time.

Most of the traffic signals in the city center of Gothenburg are mainly fixed-time signals, while traffic-actuated signalization is more frequently used outside of the city as the arrival distributions are more stochastic. The city center can be seen as a grid with streets and crossroads and therefore it is more convenient with fixed-time signalization.

6.4. Traffic detectors

Detectors for pedestrians and cyclists are limited and not used in many of the city's signalized intersections due to them being time-controlled signals. Vehicles are mainly detected by an inductive loop detector which consists of a loop of wire embedded in the road. It is connected to a detector which works on the principle of electromagnetic induction. This is an inexpensive and simple technique for identifying vehicles. Radio Frequency Identification (RFID) is used to detect trams. A GPS device, which is linked to an online map of the city,

is used to identify buses. The bus can report whenever it reaches a specific point. The information is then transferred to a cloud solution, which forwards it to a traffic light that indicates the arrival of green time.

Push buttons as detectors work differently depending on how the traffic signal works. There is a schedule for what will happen in under one minute. There are time slots in which different functions can be scheduled. When a push button is used, the traffic signal system is notified that there is a need for a green signal and pedestrians want to cross. The first available time slot will then be distributed to it. However, there must be enough time for the vehicles to evacuate the intersection, which can increase the risk of pedestrians and cyclists experiencing long waiting times. The fundamental principle is that bicycle loop detectors and push buttons should be installed wherever practical and possible, and if they do not interfere with public transportation. It is not always possible to prioritize bicycles because sometimes it conflicts with public transport, which has the highest priority.

Sometimes, cyclists are prioritized even in the absence of an installed bicycle detector. Through a method known as over-registration, they can still be given the same priority as public transportation. This process is based on tram drivers and their location ahead of an intersection. To receive priority and a green light, they have to register their location through a detector before approaching the intersection. This will automatically register the position of parallel cyclists, giving them the green light at the same time.

Installing a bicycle loop detector can be difficult when there is a multi-lane bicycle path (right, straight, left) because it is not possible to predict which direction a cyclist will take. A study was conducted in Gothenburg to see if it is possible to detect a cyclist that has different choices of direction, and the results were not favorable. Furthermore, inductive loops in the ground may occasionally not work properly or break. However, there is a monitoring system that alerts if a loop is not functioning as it should. The Urban Environment Department has not conducted a study on how well bicycle detectors work. However, no complaint has been reported so far.

Camera detectors are not used for several reasons. The main reason is that it has a higher risk of detecting wrong, thus giving unnecessary red light, and longer waiting times. A better alternative would be radars and infrared detection. This will make the system more adaptive, which in turn can reduce the time for congestion. Gothenburg City cooperates with other cities in order to advance the existing detectors and implement additional ones. Since detectors are not required in time-controlled facilities, the idea is to have detectors where they are functional and in traffic-controlled areas. The City of Gothenburg is collaborating with both the City of Stockholm and the City of Malmö to explore the use of above-ground detection. The plan is to implement it in Gothenburg in the future and conduct pilot projects where the development of AI usage is investigated. There is an initiative within the EU to research connected traffic signals, autonomous cars, and how to detect the number of vulnerable road users.

In Sweden, there is often a reluctance to adopt new technologies, even those who have proven effective in other countries. There is a tendency to prefer the familiarity of current systems and favor keeping things as they are. This resistance to change may stem from a desire to stick with known methods and an aversion to unfamiliar changes. This conservative approach can sometimes hinder the implementation of innovative solutions for pedestrians and cyclists that could enhance safety and efficiency.

7. Case study – Ullevigatan-Skånegatan

This chapter presents the case study of the signalized intersection Ullevigatan-Skånegatan. The chapter is divided into three subchapters: description of the area, results of interviews, and observations.

7.1. Ullevigatan-Skånegatan – intersection description

The intersection Ullevi-Skånegatan is a four-way intersection located in central Gothenburg city, see *Figure 4*. The intersection is a very busy area due to traffic from pedestrians, cyclists, trams, buses, cars, and other motorized vehicles. It has a total of 14 car lanes, 4 tramways, and 3 bicycle/pedestrian lanes. The lanes of Ullevigatan, from west to east, lead to the highway European route E6. From east to west, the same road leads to the central train station, Centralstationen, and shopping center, Nordstan. The lanes of Skånegatan, from north to south, lead to a major transport hub, Korsvägen. North of Skånegatan is a residential area. The speed limit of the intersection in all directions is 50 km/h (NVDB, 2024).



Figure 4. Satellite map of Ullevigatan-Skånegatan in Gothenburg marked in a red circle (Google Maps).

7.2. Results of interviews

A total of 42 pedestrians were interviewed on the west crosswalk of the intersection, marked in red in *Figure 5*. The pedestrians were chosen randomly from all age groups and genders to get a representation of the people crossing the road and an overall perception of the intersection. They were interviewed right after crossing the road. Observations were made both on the west crosswalk and on the south crosswalk, marked in blue in *Figure 5*.

The interview results are divided into two parts. The first part is about their experienced safety, waiting time, and green time. The second part is about their thoughts and concerns regarding traffic safety.

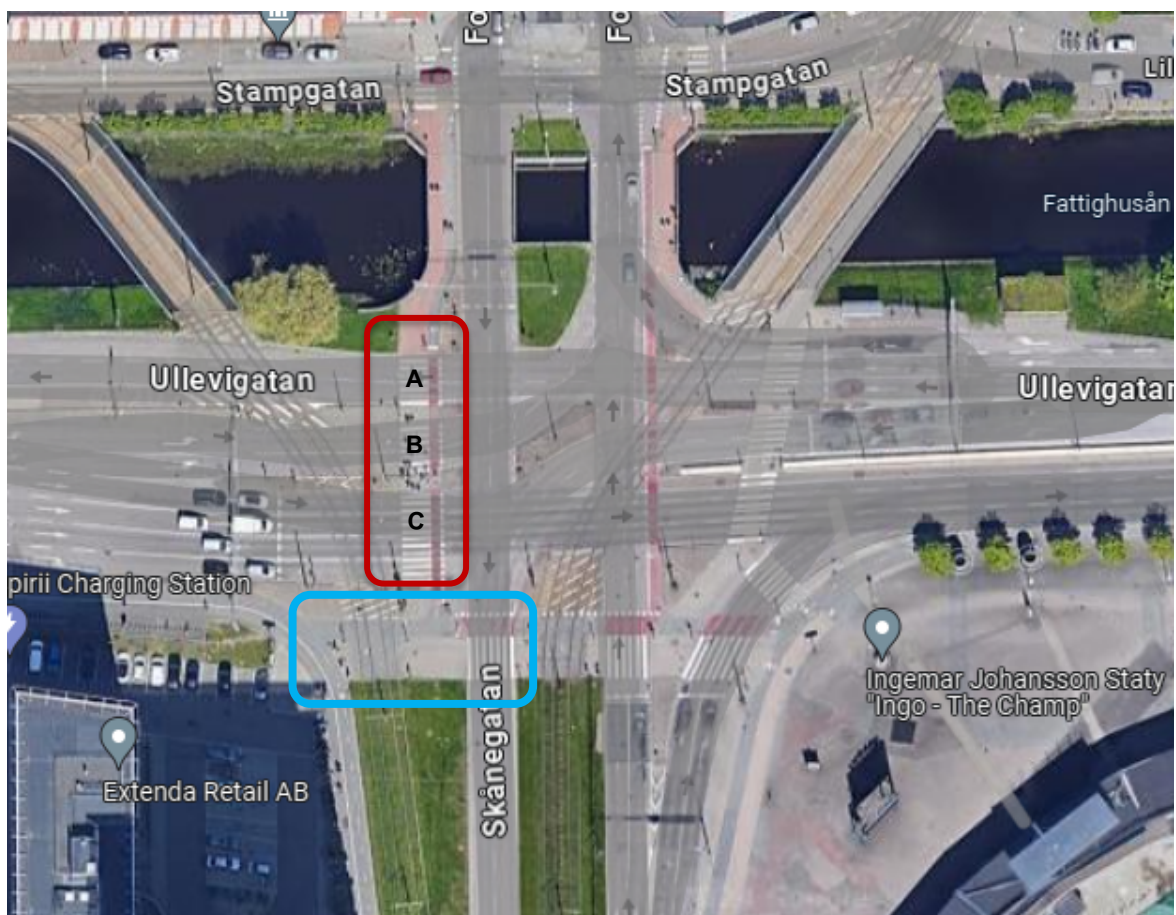


Figure 5. Satellite map over Ullevigatan-Skånegatan. The interviews are based on the area marked in red. The crosswalk is divided into three parts, A, B, and C. Observations were made in the areas marked in red and blue.

7.2.1. Experienced safety, waiting time, and green time

This subchapter describes the interviewees perceptions of safety, waiting time, and green time, of the intersection from the interviews.

Question 1. “How safe do you feel crossing this intersection? Safe, less safe, or not safe?”

When asked how safe they felt crossing the intersection they were given a scale that included the options safe, less safe, and not safe. 17 answered safe, 17 answered less safe, and 8 answered not safe, see *Table 4*. The pedestrians had no additional comments to the question as the question was phrased to obtain one of the options as an answer.

Table 4. Experienced safety of pedestrians in Ullevigatan-Skånegatan. 42 answers.

| | Safe | Less safe | Not safe |
|---|------|-----------|----------|
| How safe do you feel crossing this intersection? | 40% | 40% | 20% |

Question 2. “Do you experience the waiting time to be long?”

When asked if they experience the waiting time to be long, 25 answered yes, and 17 answered no. See *Table 5*. Most of them only answered either yes or no, but a few elaborated their answers. One pedestrian answered, “Yes, especially when the trams are coming, then it feels like minutes”. Another pedestrian stated, “It is way too long!”.

Table 5. Experienced waiting time of pedestrians in Ullevigatan-Skånegatan. 42 answers.

| | Yes | No |
|---|-----|-----|
| Do you experience the waiting time to be long? | 60% | 40% |

Question 3. “Do you think there is enough time to cross the intersection safely?”

To the question of whether they think that there is enough time to cross the overall answers were 23 yes and 19 no, see *Table 6*. Many of the people who answered yes elaborated on their answers and said that there is enough time for them to cross but do not think that older people or people with disabilities would have enough time to cross. One pedestrian said, “It is enough time for me, but I don’t think it is enough time for older people or people that walk slow. Sometimes it is very short green time. Improvements can be done”. Another answered, “Yes, for me”. Some of them stated that there is just enough time for them. One pedestrian stated, “Yes, I made it just in time walking at my pace”.

The people who answered “no” explained that they often would have to stop at the crosswalk on one of the refuge islands. One interviewee stated “No, not often. I often have to stop in the middle.” Another person explained, “Not all the way, I need to stop at one of the refuge islands”. Some stated that they have to walk a bit faster than normal to get to the other side in time. One person said, “No, only if you hurry.”.

Table 6. Experienced green time of pedestrians in Ullevigatan-Skånegatan. 42 answers.

| | Yes | No |
|---|-----|-----|
| Do you think there is enough time to cross the intersection safely? | 55% | 45% |

7.2.2. Traffic safety - thoughts and concerns

This subchapter describes the participants' thoughts and concerns regarding traffic safety at the intersection from the interviews.

Overall safety

Question 4. “*What are your thoughts on the traffic safety of this intersection?*”

When asked about what their thought on the traffic safety of the intersection was, the pedestrians’ views on the traffic safety of the intersection varied. Most interviewees explained that they thought that the intersection was complicated and that the trams were a big contributor to that. One person said, “The trams make the intersection difficult”. Another stated, “It is tricky with the trams, if you are not used to it, you will get surprised.”

Despite thinking that the intersection was complicated, many stated that they did not have any thoughts about traffic safety and explained that they were used to the traffic at the intersection. One pedestrian said, “I have not thought about it. I am used to crossing this intersection, but I can imagine that this intersection could be tricky for some people.”. A few of them argued that even though it is a busy intersection it works if people follow the signals and rules. One pedestrian replied, “If you follow the rules, it is safe. The car traffic is messy”.

Some interviewees found the intersection to be chaotic and dangerous due to the large number of cars and lanes. People with small children experienced that the intersection was dangerous especially for children because of lowered walking speed. One interviewee answered, “It is not safe, especially when walking with children, because then you walk slower.”. Some pedestrians had complaints about the allowed speed for the cars as they felt that the cars drove very fast and argued that it was not a safe speed limit to have in central Gothenburg. One pedestrian stated, “It is too many cars and too high speed.”.

Safety features

Question 5. *“What features or function of this intersection makes you feel safe or less safe?”*

Regarding what features of the intersection made them feel safe, many people said that the traffic signals were an important feature that made them feel safer. One pedestrian said, “The traffic signals make me feel safer, nothing else”. One person explained that the road lines and push button detectors were safety features that increased the experienced safety. Other features mentioned were the traffic signal sound and the refuge islands. Several participants stated that the familiarity of how the intersection works gives them more security when crossing the intersection. One person said, “The trams give me safety because then I know that the cars can’t go, and I can cross.”. Another pedestrian replied with a similar answer, “The trams because then I know how the cars will go.”. One pedestrian answered, “To know when the traffic signals will turn.”.

There were not many mentions of the features of the intersection that made them less safe. Most participants did not have any thoughts on it. One person said, “Good that the lights and sounds work, but they don’t make me feel safer.”. One pedestrian thought that the curbs were too low and that it would be easier for the cars to drive into the pavement. Another pedestrian explained that it was sometimes difficult to know when it was green for pedestrians to cross as there were many traffic signals and it could be confused with the traffic signals for cyclists. The cyclists could have a green signal while the pedestrians have a red signal, see *Figure 6*. Uncertainty of how the trams go was also mentioned. One interviewee answered, “It feels out of sync. When the trams go, then pedestrians could also go, but it is a red signal for pedestrians. I am sure there is an explanation for it, but I don’t know. It needs optimization. Now it invites breaking the law.”



Figure 6. Traffic signals showing different signals.

Many of the interviewed pedestrians stated that the design of the intersection could be optimized to make it safer. Suggestions mentioned included extending the green time so that pedestrians have enough time to cross the intersection without having to stop on one of the refuge islands. One pedestrian said, “I don’t appreciate having to stop in the middle.”. Make the path for strollers and other assistive devices with wheels wider so that there is enough room and not risk colliding with cyclists from the bike lane. Another suggestion was lowering the speed limit. One pedestrian stated, “The cars go too fast. The speed could be changed.”. Another pedestrian said, “The intersection is very strange, it feels like a highway. Speed should be lowered.”.

Alternate routes

Question 6. “Have you taken another route to avoid this intersection?”

To the question about whether they have chosen another route to avoid the intersection almost all interviewees answered no. They explained that crossing this intersection is the fastest way and there is no better route nearby to their destination. One person explained that they could imagine taking another route, “If there were a better one nearby.”. Another said, “No, I know there is a tunnel. The intersection is tricky, but I am used to it.”. Only five people answered that they have chosen a different route before, but they rarely do. Two of them mentioned the pedestrian and bicycle tunnel (Smedmästare Karlssons gångväg) located about 350 meters east of the Ullevigatan-Skånegatan intersection as an alternate route, see *Figure 7*. One pedestrian said that they sometimes take a detour in the intersection when they know it is faster despite the longer way.

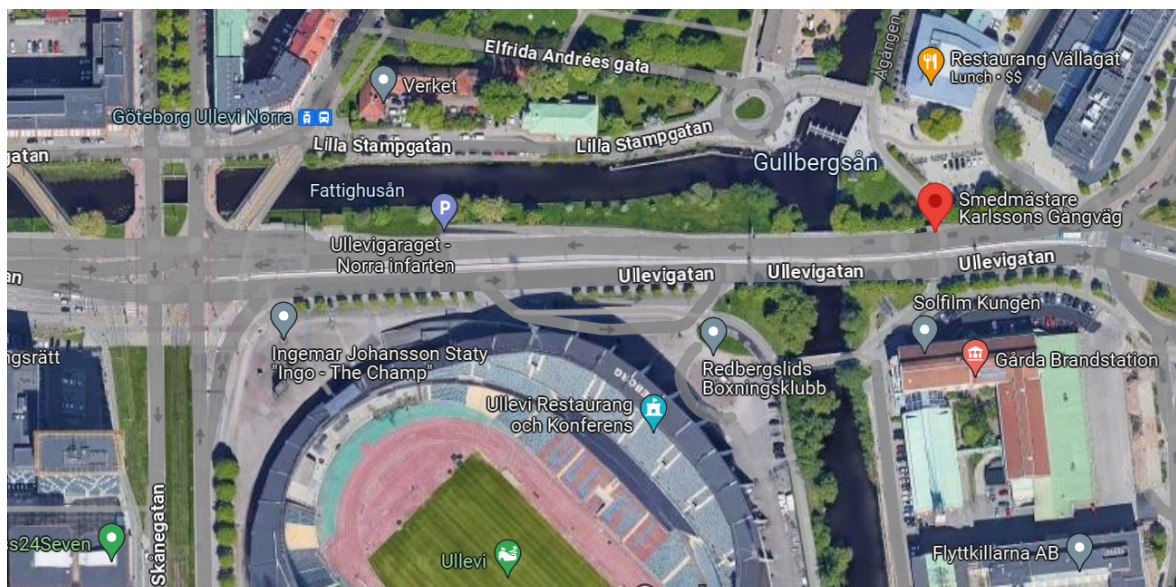


Figure 7. Smedmästare Karlssons Gångväg in Google Maps.

7.3. Observations of the intersection

This subchapter explains the observations made in the case study. It includes surrounding factors of the intersection, the design of the intersection, timings of green and waiting time, and traffic light violations.

Surrounding factors

The speed limit of the intersection is 50 km/h (NVDB, 2024). However, there are no speed limit signs in the intersection from the direction east-west, both before and after the intersection. There are signs only when entering the intersection from the north part of the intersections because the speed limit changes from 40 km/h to 50 km/h. Other parts of the intersection do not have signs due to the regulation from the Road Traffic Ordinance (Trafikförordningen) which says that the speed limit is 50 km/h in urban areas (Riksdagen, 2023).

The trams run very frequently towards and from the nearby tram stop Ullevi Södra. A tram passes the intersection almost every three to four minutes during the day. There are three tram lines passing the intersection; 2, 6, and 8. Many people travel on these tram lines through the intersection as they all reach at least one large transportation node, Centralstationen and/or Korsvägen.

Design of intersection

The west crosswalk is about 35 meters long and 6 meters wide. Parts A and B are about 9 meters long and part C is almost 17 meters long. It includes two refuge islands. On the east side of the crosswalk, there is a one-way bicycle path going towards the south of the intersection. The bicycle pathway is painted in dark red stripes as opposed to the pedestrian crosswalk which is in white. From each direction, the crosswalk has three traffic lights, one on each refuge island and one at the end of the crosswalk. There are push button detectors, one for cyclists and three for pedestrians (one at the beginning of the crosswalk and one at each refuge island). The push button detectors for pedestrians are blue and have lights around 270 degrees of the box.

The bicycle path on the west crosswalk has a push button detector for cyclists, see figure 8. The detector is yellow and installed on a console. The light is also visible on three out of four sides of the detector. The stop line for cyclists is clearly visible and have a distance from the road.



Figure 8. Push button detectors at part A of the crosswalk.

In the blue area in *Figure 5*, there are two traffic signals for crossing a way that includes a tramway. They are placed in line with the traffic signals behind and the green signals are covered, see *Figure 9*. There are no road markings on this crosswalk. The sound to warn people of incoming trams was loud and clear.



Figure 9. Traffic signals for crossing tramway.

This part of the intersection does not have a push button detector for cyclists or pedestrians, which complies with Gothenburg city's priority for trams. There was also no stop line for cyclists at the beginning of the south crosswalk, see *Figure 10*.



Figure 10. Traffic signal for cyclists in the south part of the intersection.

The next refuge island does not have push-button detectors for pedestrians or cyclists either. However, there is a stop line for cyclists. Many cyclists needed to get support from the traffic signal pole, which made their bicycles protrude over the stop line, as can be seen in *Figure 11*.



Figure 11. A cyclist leaning on the traffic signal pole.

Green time and waiting time

The green time and waiting time for crossing the west crosswalk were observed. The green time was timed three times. All three times the green time was 16 seconds until the second traffic signal turned red, while the first and last traffic signals turned red after 22 seconds. The waiting time for pedestrians varied. The waiting time was 48 seconds, 60 seconds, and the longest was 1 minute and 44 seconds.

Traffic signal violations

Another observation made was how many traffic violations were made, in both directions of the crosswalk, in ten minutes during the day. Out of 48 pedestrians, 30 went against at least one red signal, which means a traffic signal violation rate of 62.5%. People who went against the red signal were observant of the intersection and timed when to cross. Most of the traffic signal violations were made on part A of the crosswalk, see *Figure 5 and Figure 12*. This could be due to the cars' stop line being further away than the others and giving pedestrians more security to cross and a short distance to/from the next refuge island.



Figure 12. Pedestrian walking against red signal in part A of the crosswalk.

8. Discussion of results

There are many documents regarding traffic signals that city planners can use as guidance. The documents are easy to understand even for people not working in the industry. The documents are also easy to access which gives transparency on how traffic signals are supposed to be planned and designed. However, the document that is legally binding is “Transport Agency’s regulations and general advice on traffic signals” from 2014. This means other documents, such as the “Technical Handbook”, can be overlooked or not strictly followed, as they do not have the same legal weight.

The interviews gave the impression that not everyone agrees on how pedestrians and cyclists are prioritized. Most interviewees stated that the current traffic system prioritizes motorized vehicles while some stated that pedestrians and cyclists are prioritized over cars. The guidelines and recommendations advocate for a consistent approach that aims to enhance traffic safety and accessibility for all road users. For example, the “Drive When it’s Green” document emphasizes designing traffic signals to ensure that pedestrians and cyclists have sufficient green time to cross safely. The “Technical Handbook” suggests installing push-button detectors and radar devices to extend the green time as needed, as well as using cycling and pedestrian lights that are easily seen and give enough time to cross. Furthermore, the “Traffic Safety Plan” promotes better bicycle paths and slip-resistant sidewalks that prioritize the safety of pedestrians and cyclists.

The perception that vulnerable road users are prioritized may stem from these official documents, which clearly state this goal. However, given the complexity and scale of the traffic system, it can take a significant amount of time before these changes become noticeable. This delay means that while the stated goals aim to prioritize pedestrians and cyclists, the reality may still reflect a system that favors vehicles. Furthermore, it raises the possibility that the current solutions may not be as effective as intended, indicating a need for better strategies and further research to develop more effective measures to ensure the safety and prioritization of vulnerable road users.

The case study confirms that pedestrian traffic signal violation is a problem in Gothenburg. More than half of the pedestrians went against at least one signal. Most of them were very observant before crossing, only a few followed the rest of the accompanying group without checking the traffic. Although all the observed cases of traffic signal violation in the case study did not pose a major risk for a traffic accident it is still a dangerous behavior that needs to be eliminated. From the interviews in the case study, 60% of the people interviewed thought that the waiting time at the intersection was long, which can be correlated to why people choose to go against the red signal. The case study also showed the importance of clear instructions and an overview of the intersection. Clear road markings, large refuge islands, and functioning traffic signals are features that increase perceived safety. Regarding the design of the intersection in the case study, one idea could be clearer road markings, such

as stop lines, or additional road markings such as a warning for trams to remind people to be cautious of both directions.

Another factor that affects perceived traffic safety is the allowed speed limit. The standard speed limit is 50 km/h which is the reason why there are no signs set up. Even though it is common knowledge, setting up speed limit signs could potentially remind people of not driving faster than the limit, like the warning of cyclists signs. The warning of cyclists signs reminds people that cyclists from parallel pathways also have green signals, even though it should be known that a green signal without an arrow means that other road users in an intersecting way may also have a green signal. To further increase safety, the speed limit could be lowered as previous studies have shown to drastically reduce accident severity. However, this needs to be investigated as the traffic volume needs to be considered. It is important to not cause traffic congestion and compromise the level of service for other road users.

To add to the traffic safety for cyclists, installing leaning rails could be a feature to consider. Many cyclists use the traffic signal pole as support when stopping at a red signal, as can be seen in both *Figure 11* and *Figure 12*. By installing leaning rails, cyclists can stop more safely when waiting for the signal to turn green. Not being able to stop safely before the stop line, could encourage cyclists to take the risk to cross the intersection to not lose momentum.

The current traffic signal system strategy has been almost the same for four decades. The system does not account for how many vulnerable road users are waiting for a green signal at the intersection. The system only registers a need for a green signal at a crosswalk, which is a problem as the system does not weigh the number of people waiting as a factor. The ongoing research on alternate detector strategies is at other places in Sweden and Europe than Gothenburg. As Gothenburg has a clear goal to promote sustainable transport modes, it is suitable to find a sufficient solution to increase people's perceived accessibility to walking and cycling in Gothenburg. By finding a solution that can accurately detect the number of pedestrians and cyclists waiting at an intersection, it is easier to work towards a traffic system that prioritizes these vulnerable road users and thus achieves the goal that the city has set up. Hence, one suggestion is investigating different detecting systems for specifically Gothenburg as each city has different conditions and goals.

Many of the more experienced specialists in charge of traffic signals are either about to retire or have already left the company. Juniors with less experience than their predecessors are taking their positions. Therefore, it is essential to provide these newcomers opportunities to become familiar with traffic signals and make sure they have the necessary tools to efficiently manage and apply the guidelines. The "Technical Handbook" is valuable because it provides thorough advice and is updated twice every year to keep the guidelines up to date and applicable. Due to its easy accessibility and usage, this manual can work as a resource for educating newcomers with the fundamental information to operate traffic systems.

There is a noticeable lack of current and up-to-date articles on certain topics which poses a challenge for decision-makers and planners. The scarcity hinders the ability to fully understand and implement the latest advancements in technology for pedestrians and cyclists. An example of this is the limited availability of articles that explain the consequences of the implementation of the LHOVRA system, with most of the relevant literature studies dating from the late 80s to the early 00s. This gap underlines the need for more contemporary studies and publications to support informed decision-making and progress in this field.

This master's thesis has been limited in several aspects. The aim of this study was not to suggest a new technology as a solution. The focus of this thesis has been providing an understanding of the traffic system in Gothenburg regarding traffic signals and traffic safety. The thesis has also been limited to studying traffic safety for pedestrians and cyclists, not other road users. The study has been done through literature and technical reviews, interviews with experts on the topic, and a case study on a problematic intersection. Further studies are needed to get more perspective on the traffic signal system in Gothenburg, for example, interviewing more people from different companies. As this study has not studied different technologies as solutions to the traffic signal system, a suggestion is to investigate new methods to increase traffic safety for vulnerable road users and make the use of traffic signals more effective.

9. Conclusion and recommendations

One of the conclusions that can be drawn from this study is that the current traffic signal system in Gothenburg needs a more effective detecting system. To increase the use of walking and cycling as transport modes, the traffic signal system needs to consider the number of vulnerable road users. By having a system that accounts for the number of waiting for vulnerable road users, the waiting time for them will likely be reduced and the rate of traffic violations will decrease, which will increase traffic safety. However, this will require further investigation on suitable solutions for Gothenburg's traffic system.

To further increase traffic safety for both pedestrians and cyclists, this study recommends setting up speed limit signs even at intersections with the standard speed limit for urban areas. It is not sufficient to rely on the assumption that drivers automatically know the speed limit is 50 km/h in urban areas. Installing speed limit signs closer to the intersection can serve as a clear reminder for drivers, reducing the likelihood of them exceeding the speed limit. Additionally, reducing the speed limit at intersections before returning to the regular speed limit after passing through can make pedestrians and cyclists feel safer, as vehicles will not appear to be driving too fast near the crossings. This measure would enhance safety for vulnerable road users, such as pedestrians and cyclists, by ensuring that all drivers are aware of and follow the speed limits, thereby creating a safer environment at intersections. Clearer road markings and leaning rails for cyclists are also suggested to improve safety and convenience.

Furthermore, it is essential to address the inconsistency between the goals stated in the guidelines and the actual implementation. While documents like "Drive When it's Green", "Technical Handbook", and the "Traffic Safety Plan" advocate for prioritizing vulnerable road users, there is still a perceived bias towards vehicles. This indicates a need for better strategies and further research to develop effective measures.

Additionally, the guidelines should be clearer and more consistent to avoid conflicting interpretations. This will help ensure that all stakeholders are aligned in their efforts to prioritize safety for pedestrians and cyclists. Also, while the current documents provide a solid theoretical foundation, their practical application must be regularly reviewed and updated based on concrete feedback and outcomes.

In conclusion, while Gothenburg has made significant progress towards creating a safer and more accessible traffic system for vulnerable road users, there is still much work to be done. By implementing more effective detecting systems, enhancing infrastructure, clarifying guidelines, addressing speed limit measures at intersections, and ensuring comprehensive guidance for newcomers, the city can continue to improve traffic safety and encourage sustainable transport modes. Further research and continuous improvement will be key to achieving these goals and ensuring the safety of all road users in Gothenburg.

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