Bus Priority Signal Design and Control at Unconventional Intersections: A Simulation-Based Study in Jönköping

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Abstract

This thesis evaluates the efficacy of traffic management strategies at the Museirondellen and Södra Strandgatan intersections in Jönköping, Sweden, emphasizing bus prioritization and geometric design modifications. Due to their significant traffic volumes and complex designs, these intersections pose key challenges in terms of congestion and safety. Advanced traffic simulation tools are employed to assess current conditions and to explore the impacts of proposed geometric changes under various traffic scenarios, including increases of 10%, 15%, and 20% in traffic volumes. The study incorporates a survey of local drivers to gather firsthand insights into the current traffic issues and perceptions of the proposed changes, complemented by detailed geographical data and signal timing information from local databases. A new intersection design was proposed and tested through simulations, demonstrating its potential to alleviate congestion and enhance public transport efficiency. The research aims to analyze existing traffic inefficiencies, evaluate the effectiveness of bus prioritization, and assess the new geometric design's impact on traffic flow and safety. The findings are intended to provide evidence-based recommendations that could influence urban planning and policy-making in Jönköping and other cities with similar challenges. The significance of this study extends to its approach to integrating bus traffic within urban intersections and optimizing intersection geometries to foster sustainable traffic systems. Expected outcomes include improved urban mobility, enhanced road safety, and actionable insights for future enhancements in traffic management in urban settings.

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We are particularly grateful to Jönköping Municipality for allowing us access to their data, which was crucial for our study.

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1 Introduction

Urban traffic management stands at the forefront of sustainable urban planning, directly influencing the economic vitality, environmental sustainability, and quality of life in cities. The advent of rapid urbanization has escalated challenges such as congestion, air pollution, and traffic-related accidents, pressing city planners to devise intelligent traffic management strategies (Litman, 2020). Effective urban traffic control is not only about managing the flow of cars but also involves optimizing signalized intersections, integrating various modes of transportation, and ensuring the safety and efficiency of public transit systems through strategies like bus prioritization (Rodier et al., 2019).

Signalized intersections are critical nodes within urban traffic networks, where the design and operational strategies can significantly impact traffic flow and safety. These intersections use traffic signals to manage the movements of different streams of traffic, including vehicles, pedestrians, and cyclists, making them complex but essential components of urban infrastructure (Garber & Hoel, 2018). Properly implemented, these systems reduce delays and accidents, and when coupled with bus prioritization measures, they can significantly enhance the efficiency and appeal of public transportation. Bus prioritization at signalized intersections, such as giving buses advanced green lights or dedicated lanes, helps in reducing travel times for public transit and making it a more competitive choice compared to private vehicles (Cervero & Guerra, 2011).

The city of Jönköping, Sweden, with its significant challenges at key intersections like Museirondellen and Södra Strandgatan, provides a practical context for this study. These intersections are not only high-volume traffic areas but also incorporate complex designs that include signalized configurations and extensive bus traffic. This research focuses on evaluating and optimizing these intersections through innovative traffic management strategies, including the prioritization of buses and the assessment of geometric modifications to improve traffic flow and safety.

The Museirondellen and Södra Strandgatan intersections are characterized by their design and function, incorporating elements like a signalized throughabout and adjacent non-signalized intersections. These features create a complex traffic management scenario characterized by frequent congestion, navigational challenges, and significant bus traffic flows. Addressing these challenges through effective traffic management strategies is crucial for improving traffic flow and enhancing road safety.

The primary objectives of this thesis are to conduct an in-depth analysis of current traffic conditions at these intersections to identify primary areas of congestion and key safety issues; evaluate the effectiveness of bus prioritization strategies at the Museirondellen throughabout in improving bus travel times and reducing general traffic delays; assess the impact of proposed geometric changes at both intersections on improving navigational clarity, reducing driver confusion, and enhancing safety; and explore the long-term effects of these traffic management strategies on meeting the growing demands of urban traffic and assess their sustainability in the context of Jönköping's urban development.

The significance of this research lies in its potential to provide insights that could influence future urban planning and policy-making in Jönköping and other cities with similar traffic challenges. By offering evidence-based recommendations, the study aims to contribute to the broader field of traffic engineering and urban planning, advocating for innovative solutions to enhance urban mobility and quality of life. The findings from this study are expected to provide valuable guidelines for urban traffic management, particularly in optimizing the integration of bus traffic within busy urban intersections, and designing intersection geometries that improve traffic flow and safety. Ultimately, this research seeks to contribute to the development of smarter, more efficient urban traffic systems that can adapt to future challenges.

1.1 Aim

The primary aim of this thesis is to evaluate the traffic management strategies at the Museirondellen and Södra Strandgatan intersections in Jönköping, Sweden, with a particular focus on the effectiveness of bus prioritization and geometric design modifications. This study seeks to assess how these strategies influence traffic flow, safety, and overall efficiency, aiming to provide evidence-based recommendations for future urban planning and traffic system enhancements. By integrating advanced simulation tools and empirical data analysis, the thesis focus on:

- Analysis of the current traffic patterns and identify key areas of congestion and safety concerns at these intersections.
- Evaluate the effectiveness of proposed geometric changes in enhancing navigational clarity and reducing driver confusion.
- Explore the long-term sustainability of the implemented traffic management strategies in light of urban growth and increased traffic demands.

1.2 Research questions

1. *How does the current traffic configuration and the geometric design at the Museirondellen and Södra Strandgatan intersections in Jönköping, Sweden, affect speed, density, and queue length, and what implications do these factors have on overall traffic flow?*

2. *How do potential traffic volume increases impact queuing, delays, and overall efficiency in the studied area?*

3. *In what ways does the current geometric design of the non-signalized intersection at Södra Strandgatan contribute to driver confusion, and what potential modifications could enhance navigational clarity and traffic safety?*

1.3 Data collection

The data collection process for the traffic simulation model validation at the Museirondellen and Södra Strandgatan intersections in Jönköping is extensive and thoroughly planned to ensure high fidelity in modeling real-world conditions. This process begins with acquiring baseline traffic data, which includes traffic counts, vehicle classifications, and traffic patterns, primarily focusing on peak traffic periods. This data is sourced from Jönköping municipality and Trafikverket NVDB databases, which provide a foundational understanding of the traffic dynamics at these intersections.

Additionally, Jönköping municipality supplied a detailed DWG map of the area. This map is crucial for accurately representing the geographical layout and infrastructural specifics of the intersections in the simulation model, enhancing the contextual accuracy of the traffic analysis. The municipality also provided crucial detector data, signal plans, and signal data in the form of PDF files. This information is instrumental in understanding the existing signal timing and coordination, which directly influences traffic flow and control strategies at these intersections. For further investigation for the data refer to Appendix A Figure 38 and Figure 39.

Field observations complement these data sources and add a layer of granularity to the traffic assessment. On February 29, 2024, detailed video recordings of traffic flow were captured during a peak period from 4:00 PM to 5:00 PM. These observations are critical for understanding real-time traffic behaviors, including lane usage and turning movements, which are not always apparent from database information alone.

Further enhancing the data collection, a comprehensive field study was conducted during evening rush hour. This study not only involved counting vehicles but also focused on observing the interactions among different types of road users and the operational impact of traffic signals on traffic flow and safety. These field studies provide high-resolution data that captures the complex behaviors and interactions within the traffic system, offering valuable insights into the actual operating conditions at the intersections.

2 Site Description

This thesis delves into the distinctive traffic configuration in Jönköping, Sweden, with a particular focus on the interconnected intersections of Museirondellen, a signalized roundabout (throughabout), and an adjacent intersection at Södra Strandgatan (see Figure 1).

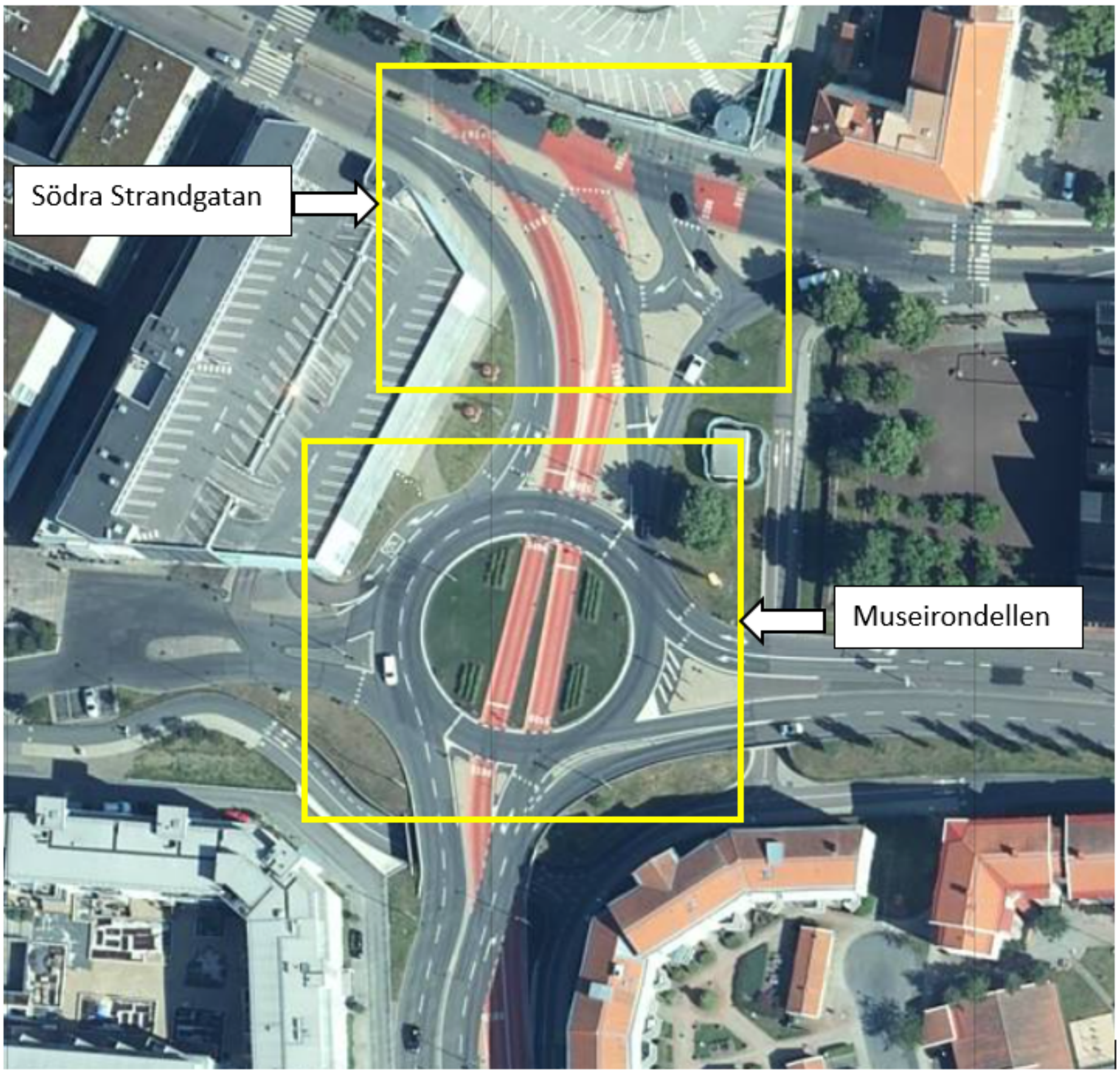

Figure 1: Museirondellen and Södra Strandgatan intersections (Minkarta, 2024)

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2.1 Geographical Context and Layout

Jönköping, situated in the central southern part of Sweden, boasts a population of 146,000 residents as reported by the Jönköping Municipality in 2023. The Museirondellen and the Södra Strandgatan intersections are located in the city's heart, a bustling urban center (see Figure 2)

Figure 2: Jönköping and site location (Google earth 2024)

The Museirondellen is distinguished by its unique design featuring a split central island, deviating markedly from traditional roundabout designs (see Figure 3).

Figure 3: Museirondellen surrounding streets (Minkarta 2024)

This roundabout is a convergence point for six streets: Södra Strandgatan, Slottsgatan, Odengatan, Parking house Atollen, Lillsjöplan, and Öster Strandgatan. Its design also integrates two bus lanes. The combination of these streets and the roundabout's novel layout results in a complex traffic flow pattern.

Adjacent to Museirondellen is a crucial intersection on Södra Strandgatan (illustrated in Figure 4). This intersection interlinks four streets and includes access points to the Smedjan parking house and bus lanes originating from Slottsgatan and Södra Strandgatan. The intricacy of this intersection, coupled with the proximity to the roundabout, creates a multifaceted navigational challenge for drivers.

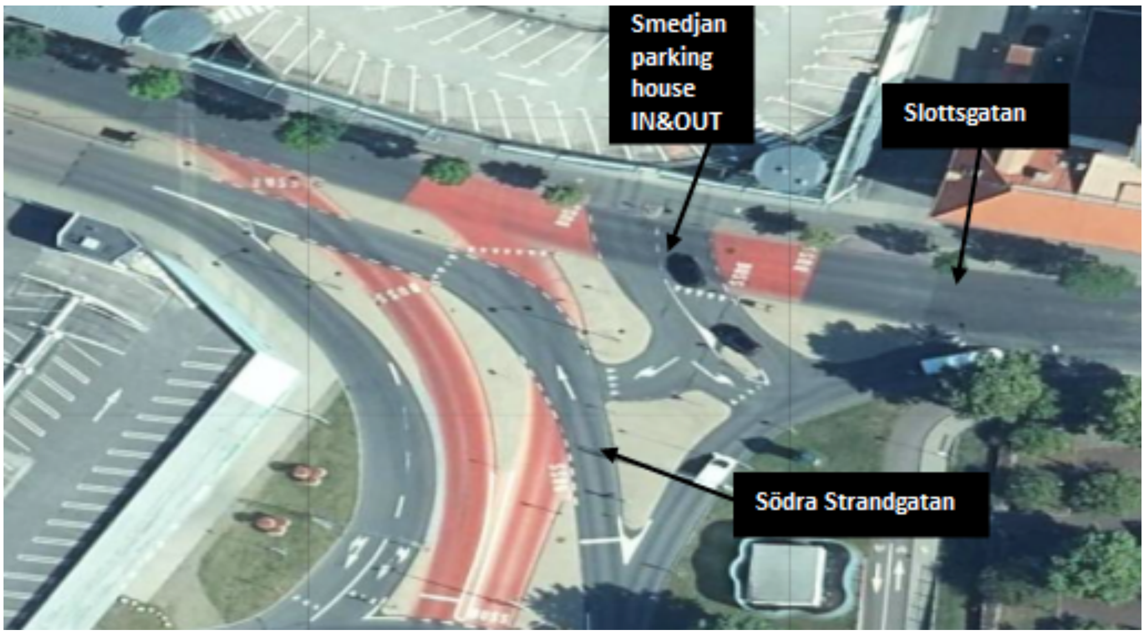

Figure 4: Södra Strandgatan surrounding streets (Minkarta, 2024)

The ingress and egress points of the Smedjan parking house, in particular, presents a notable complexity in the traffic design of the area. Located in close proximity to the bus lanes, this entrance creates a challenging navigation scenario, as drivers must navigate through the mixed traffic flows while also contending with the specific demands of entering and exiting the parking structure.

2.2 Public Perception and Media Attention

The Museirondellen and Södra Strandgatan intersections have not only captured the attention of local media but have also been featured in international news outlets. A notable instance is the coverage by the Danish newspaper B.T., which reported on the roundabout on April 10, 2015, following its inauguration (see Figure 5). B.T. highlighted the confusion and disorientation experienced by drivers, especially during instances when snow concealed the red lanes designated for buses. For more details on this coverage, see the article "Rundtosset: Er dette den mest forvirrende rundkørsel, du har set?" by B.T link: [Rundtosset: Er dette den mest forvirrende rundkørsel, du har set? | BT Utroligt men sandt - www.bt.dk](#).

Figure 5: Newspapers talking about the confusing of Museirondellen and Södra Strandgatan intersections.

Similarly, Sweden's Television (SVT) addressed the complexities of navigating the newly opened roundabout in a segment titled "Confusion in the new roundabout in Jönköping," broadcast a few days after its opening on November 14, 2014. The local newspaper, Jönköping Posten, has also consistently covered the intersections, providing insights into the community's reactions and adjustments to the new traffic layout. Further details can be found in SVT's coverage link: [Förvirring i nya rondellen i Jönköping | SVT Nyheter](#)

Furthermore, Aftonbladet, a widely circulated Swedish daily tabloid, has featured articles about these intersections. Known for being one of the largest daily newspapers in the Nordic countries, Aftonbladet's coverage underscores the significance and widespread interest in the traffic dynamics and design of these intersections in Jönköping. More information can be found in the article "Jönköpings nya rondell har blivit en nationell snackis" from Aftonbladet link: Jönköpings nya rondell har blivit en nationell snackis (aftonbladet.se).

This extensive media attention from both local and international sources reflects the public's keen interest and the challenges posed by these intersections, particularly in terms of driver adaptation and traffic management. The coverage serves as a testament to the intersections' impact and the broader implications for urban traffic design and navigation.

2.3 Surrounding Environment

The intersection at Museirondellen and Södra Strandgatan, is surrounded by a diverse urban environment. This is detailed in a map using a color-coded system, see Figure 6. The area is important for understanding the city's complex and varied urban layout.

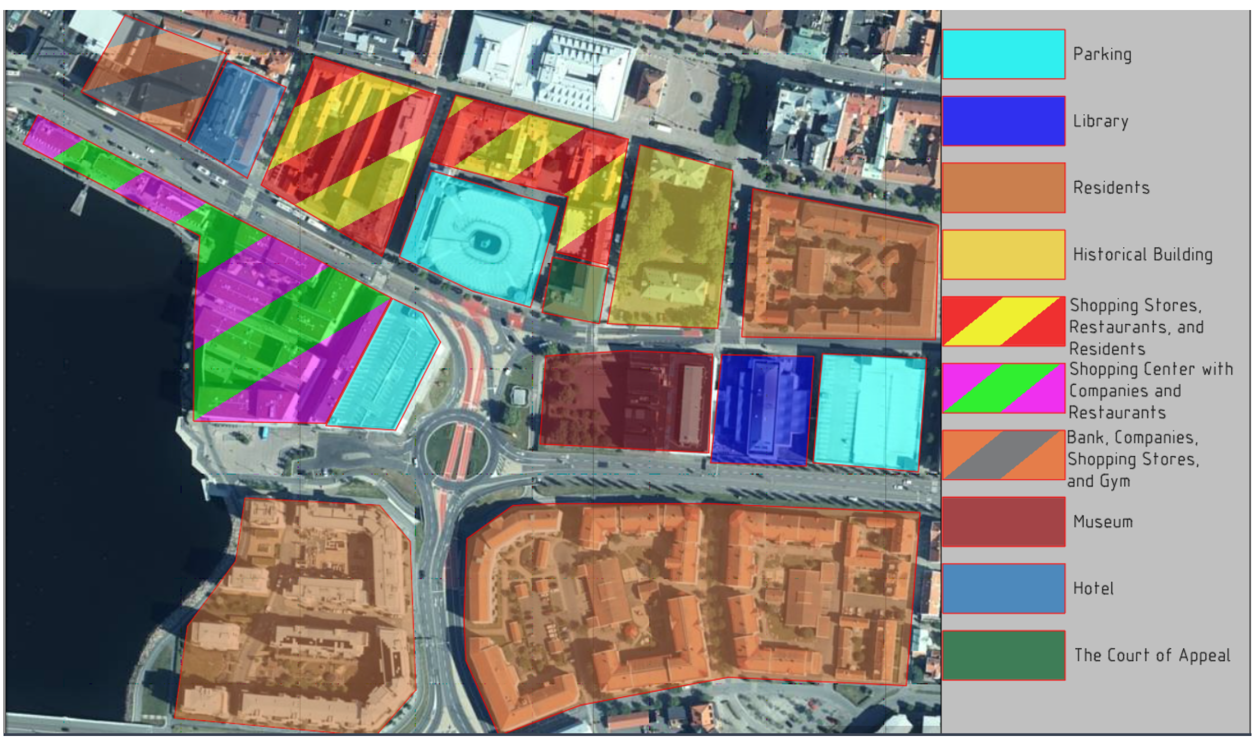

Figure 6:Color coding of surrounding buildings

Three key parking areas - Atollen, Smedjan, and the library parking - are shown in cyan color on the map. These parking places are essential for managing the large number of vehicles in this area.

The Smedjan parking, near the bus lanes, is particularly notable. Its position creates traffic challenges, especially for drivers entering and leaving the parking. In close proximity to these parking areas, the historic Göta Court, color-coded in gold or sand yellow, stands as a testament to the city's rich cultural heritage. This esteemed building encompasses the original 1650 court structure and a 19th-century archive addition, marking a significant historical footprint in the landscape. The map shows the Jönköping County Museum in maroon color. This museum is important for the culture of the region, showing local history and art. Nearby, the Jönköping Library is marked in deep blue, indicating its role as an important place for learning and community information. Significantly, areas combining Banks, Companies, Shopping Stores, and Gyms are represented with a pattern of striped orange and gray. This color scheme signifies the dynamic and multifunctional nature of these spaces, blending various aspects of urban life. The map also highlights other important urban features. Shopping centers, businesses, and restaurants are indicated in purple with green highlights. This shows areas of commercial activity and social gathering. Hotels are marked in royal blue, pointing out the city's hospitality services. Residential areas are in beige or light brown, showing where people live within the city. Areas that mix shopping, restaurants, and residences are uniquely shown using a red to yellow. This illustrates the lively and diverse nature of these mixed-use areas. This color-coded map of the Museirondellen and Södra Strandgatan intersection encapsulates the essence of urban complexity. It blends cultural, commercial, and infrastructural elements, each contributing to the area's unique challenges in traffic management and urban planning. Such a detailed representation underscores the necessity for innovative and thoughtful approaches in city development, ensuring a balance between preserving historical heritage and accommodating modern urban needs.

2.4 History

The development of the Museirondellen and Södra Strandgatan intersections, which was officially opened on November 12, 2014, represents a pivotal moment in the evolution of Jönköping City's traffic management and urban planning. This intersection's construction in 2014 marked a significant transformation from its previous state.

Looking back to 1975, the area was considerably different, with notable changes occurring over the years, particularly in terms of building development. A substantial increase in the number of buildings, especially shopping stores and restaurants, has been observed, indicating a shift towards a more commercial and vibrant urban landscape. See Figure 7.

Figure 7: Site area in 1975 (Länmateriet, 2024) *Site area in 2024 (Länmateriet, 2024)*

Prior to the 2014 redevelopment, the intersection functioned with a traffic light system. At that time, there were no designated bus lanes, nor was there any prioritization for buses in the intersection. This aspect of the intersection's design highlights the evolution of urban transport infrastructure, catering to the increasing demands of public transportation. Furthermore, the traffic demand in the area has escalated significantly compared to the past. Before the 2014 reconstruction, the volume of traffic was considerably lower, reflecting the urban growth and increased mobility needs of the city over the years.

The transformation of the Museirondellen and Södra Strandgatan intersection from a conventional traffic light junction to its current state underscores the dynamic nature of urban development. It reflects the city's response to changing transportation needs and the evolution of its urban landscape, demonstrating a shift towards more sophisticated traffic management and urban planning methodologies.

3 Literature review

This section looks closely at how signalized intersections have changed and how they affect city traffic control, focusing on Throughabouts and their implementation, buss prioritization, and challenges in intersection design. It starts by looking at the history of these intersections, from their start in the early 1900s to their modern forms. These intersections are key in managing traffic and improving road safety and have developed a lot to keep up with growing city needs.

Then, the review examines different intersection designs, from usual signalized ones to newer ones like throughabouts. It checks how well these designs work for managing traffic and supporting public transport, which is particularly important in city planning today. It gives special attention to how these intersections fit into cities, with examples like a signalized roundabout that helps buses, to show how they work in real life.

In the end, this review aims to give a full picture of signalized intersections. It investigates their technical progress and how important they are for modern city planning and traffic engineering. By doing this, the review hopes to offer useful knowledge, especially for improving city movement and traffic control in fast-changing urban areas.

3.1 Fundamentals on Signalized Intersections

The concept of signalized intersections appeared with the advent of motor vehicles. As early as the 1860s, gas-lit signals were used in London to control the flow of horse-drawn carriages. However, the first electric traffic signal was installed in Cleveland, Ohio in 1914. This innovation marked the beginning of modern traffic control systems (Garber & Hoel, 2018). Over the years, the design and technology of signalized intersections have evolved significantly, incorporating advanced sensors, computerized control systems, and adaptive algorithms to optimize traffic flow.

Signalized intersections typically consist of several key components: traffic lights, detection systems, controllers, and pedestrian signals. Traffic lights are the most visible element, displaying assorted colors (red, yellow, and green) to direct traffic. Detection systems, such as inductive loops and cameras, provide real-time data on traffic conditions, which are used by controllers to adjust signal timings. Pedestrian signals ensure safe crossing opportunities for foot traffic. It utilizes traffic lights to control the movement of vehicles and pedestrians. These intersections are typically found at junctions where two or more roads meet, and traffic flow is too heavy or complex to be managed by less controlled means like roundabouts or stop signs. The primary purpose of signalized intersections is to facilitate the orderly movement of traffic, prevent the stream of traffic from one direction from continuously blocking other movements, and ensure a balanced distribution of green time to various traffic movements (Coates, Yi, Koganti, & Du, 2012).

One of the key benefits of signalized intersections is the enhancement of safety. By dictating the right of way, these intersections reduce the likelihood of conflicts that could lead to accidents. Signalized intersections are particularly beneficial in managing high-traffic areas, where the volume of vehicles and pedestrians necessitates a more regulated approach to ensure safety and efficiency. The signals enforce a systematic sharing of the intersection, which helps in reducing the potential for collisions, particularly angle and left-turn collisions (Alshayeb, S., Stevanovic, A., Stevanovic, J., & Dobrota, N, 2023).

The installation and operation of signalized intersections are guided by various standards and best practices. In the United States, the Manual on Uniform Traffic Control Devices (MUTCD) sets forth guidelines for the design and use of traffic signals. Additionally, the American Association of State Highway and Transportation Officials (AASHTO) provides design specifications for roadways, including signalized intersections. These standards ensure consistency, safety, and efficiency in traffic management across different jurisdictions (AASHTO, 2018).

Signalized intersections also play a critical role in intelligent transportation systems (ITS). They can be integrated with other ITS components, such as advanced traveller information systems and emergency vehicle preemption systems, to create a more efficient and responsive traffic network. For example, signal priority can be given to buses in a bus rapid transit (BRT) system to improve public transportation efficiency (Agafonov, A., Yumaganov, A., & Myasnikov, V, 2023).

Despite their benefits, signalized intersections also present challenges. Incorrectly designed or poorly timed signals can lead to increased congestion and delays. Additionally, intersections are often sites of vehicle-pedestrian and vehicle-vehicle conflicts, leading to safety concerns. As such, ongoing research in traffic engineering focuses on optimizing signal timings, improving pedestrian and cyclist safety, and integrating emerging technologies like connected and autonomous vehicles into intersection management (S Cheng, C., Du, Y., Sun, L., & Ji, Y, 2016).

Signalized intersections come in diverse designs, each tailored to the specific requirements of the location. The most common design is the traditional crossroads configuration, where two roads intersect at right angles. However, other designs include T-junctions, staggered junctions, and multi-arm junctions, each offering unique advantages depending on the traffic patterns and physical constraints of the location (Coates, Yi, Koganti, & Du, 2012). An integral aspect of signalized intersections is signal phasing and timing. Phasing refers to the grouping of traffic movements given the right of way simultaneously during a signal cycle. Efficient signal phasing is essential to maximize the capacity of an intersection and minimize delays. For example, a simple two-phase system might have one phase for north-south movements and another for east-west movements. More complex intersections might have additional phases for protected left turns or pedestrian crossings (Coates, Yi, Koganti, & Du, 2012).

The timing of these phases is equally crucial. The signal cycle length and the distribution of green time among phases must be carefully calibrated based on traffic volumes, patterns, and the specific needs of the intersection. Effective timing can significantly reduce delays and improve the overall efficiency of the intersection (Alshayeb, S., Stevanovic, A., Stevanovic, J., & Dobrota, N, 2023).

Advancements in technology have led to the development of adaptive signal control systems, which adjust signal timings in real-time based on current traffic conditions. These systems use sensors to detect traffic volumes and adjust the signal phases, accordingly, thus improving the responsiveness of the intersection to dynamic traffic patterns. Adaptive signal control systems can significantly enhance the efficiency of signalized intersections, particularly in areas with fluctuating traffic volumes (Feng, Y., Head, K. L., Khoshmagham, S., & Zamanipour, M., 2015).

Signalized intersections also have notable environmental and economic implications. Efficient signal timing can lead to reduced idling and shorter travel times, which in turn can lower vehicle emissions and fuel consumption. This not only contributes to better air quality but also offers economic benefits in terms of reduced fuel costs and enhanced productivity due to less time spent in traffic (Coates, Yi, Koganti, & Du, 2012).

3.2 Throughabouts

Throughabouts represent a change in thinking in roundabout design, a concept innovatively introduced by Zakeri and Choupani (2021). This design is characterized by a split central island, a feature that fundamentally differentiates it from traditional roundabouts see Figure 8.

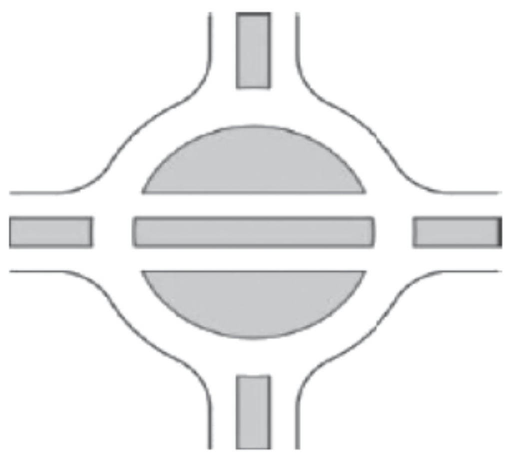

Figure 8: Throughabout (Zakeri and Chaupani 2021)

The central idea behind throughabouts is to streamline traffic flow while simultaneously accommodating Bus Rapid Transit (BRT) systems more effectively, an aspect explored in-depth by researchers like Levinson et al. (2002) and Cervero (2006). The distinct configuration of throughabouts facilitates a more organized segregation of traffic, allowing for a smoother flow of vehicles and a more efficient transit of BRT systems, thereby addressing some of the most pressing challenges in urban traffic congestion. The adaptability of throughabouts to various urban landscapes, as emphasized by Ma et al. (2017) and Elhassy et al. (2020), highlights their versatility in managing traffic under different conditions, from high-density urban centers to suburban areas.

The implementation of throughabouts is a complex process that involves careful consideration of various factors. One of the most critical aspects is the integration of advanced traffic signal systems. These systems, as studied by Li et al. (2015) and Zakeri & Choupani (2021), need to be meticulously synchronized with larger urban traffic networks to ensure an uninterrupted and efficient flow of traffic. This synchronization becomes particularly vital in areas where BRT systems are predominant, as highlighted in the research by Hidalgo and Gutiérrez (2013), who stress the growing significance of BRT systems in urban transport infrastructures.

In designing throughabouts, the safety and accessibility for non-motorized users, such as pedestrians and cyclists, must be given paramount importance. The design must incorporate comprehensive pedestrian crossings, cycling paths, and various safety measures to ensure an inclusive environment for all forms of traffic. This consideration, detailed in the work of Sisiopiku & Akin (2003), is critical for building roundabouts that are not only efficient for vehicular traffic but also safe and accessible for pedestrians and cyclists.

The advantages of throughabouts extend to various aspects of urban life. They significantly improve the efficiency of public transportation systems, especially BRTs (Bus Rapid Transit), by minimizing delays and enhancing punctuality, thereby contributing to a more reliable public transportation network (Aakre & Aakre, 2017). Additionally, through the reduction in vehicular congestion and smoother traffic flow, throughabouts can contribute to a decrease in CO_2 emissions, underlining their role in promoting environmental sustainability in urban transportation.

Despite these benefits, the implementation of throughabouts comes with its own set of challenges. Key among these is the management of traffic signals in such a way that they complement the new traffic patterns. Another significant challenge is ensuring public compliance and understanding of these new traffic layouts. As Gitelman & Korchatov (2021) point out, educating the public and adapting driver behaviour to new traffic configurations is crucial for the successful functioning of throughabouts. In comparison with traditional intersections, throughabouts offer marked improvements in both efficiency and safety. Research by Retting et al. (2002) and Daniels et al. (2010) has demonstrated that traditional intersections are often less efficient and more prone to accidents. Throughabouts, with their enhanced traffic flow and safety features, present a compelling alternative, especially in areas struggling with high traffic volumes and safety concerns.

Looking at the broader picture, the success of throughabouts is contingent upon their acceptance by the community. The importance of public education and behavioural adaptation to new traffic systems, as emphasized by Taubman et al. (2007), is integral to the smooth transition to these new arrangements. Programs focusing on public awareness, driver education, and the use of simulation-based training methods (Kay et al., 2009) are essential in acclimatizing the public to throughabouts. As cities continue to expand and face new traffic management challenges, throughabouts emerge as a crucial tool in shaping sustainable, efficient, and safe urban traffic systems.

In the realm of traffic management and urban planning, throughabouts have been subject to various studies and implementations, shedding light on their practical applications and efficacy in diverse contexts. Notably, the research conducted by Zakeri and Choupani (2021) stands out as a significant case study that offers detailed insights into the operational evaluation of throughabouts, particularly emphasizing their role in prioritizing public transport in standard roundabouts.

In their study, Zakeri and Choupani (2021) conducted a thorough investigation into a throughabout's impact on traffic flow and public transportation efficiency. This research is pivotal as it provides empirical evidence on how throughabouts can significantly improve travel time for both public and private transport. The study's location in Shahrood, Iran, provides a unique context, yet the findings have broader implications, resonating with urban centers globally experiencing similar traffic challenges. The research employed advanced microsimulation tools, specifically AIMSUN software, to model traffic flow and assess the throughabout's performance under various traffic volumes. This methodology allowed for a detailed analysis of travel times, queue lengths, and overall traffic efficiency, offering a comprehensive understanding of the throughabout’s impact in real-world scenarios.

The study's findings revealed that throughabouts improved travel times and maintained steady traffic flow at various volume levels. This improvement was not limited to public transport; private vehicles also benefited from the smoother traffic flow facilitated by the throughabout design. Importantly, the study highlighted the throughabout's ability to keep traffic flowing, even under high-volume conditions, which is a critical consideration for urban areas grappling with congestion issues. The research by Zakeri and Choupani (2021) thus provides a valuable case study in understanding the practical implications and benefits of throughabouts in urban traffic management.

3.3 Bus Prioritization

Bus prioritization in urban transportation planning is a concept that revolves around optimizing the flow of buses through intersection designs and signal optimizations (Wahlstedt, J., 2011). This approach is driven by the growing necessity to manage urban traffic congestion, environmental concerns, and the demand for efficient public transportation systems. The fundamental principle of bus prioritization is to enhance the operational efficiency of bus transit by reducing travel time and improving service regularity, thereby making public transport a more attractive option for commuters. This concept is integral to the strategic planning of urban transportation, emphasizing the critical role of buses in the mobility network (Hamurcu, M., & Eren, T, 2020).

The rationale for bus prioritization is deeply rooted in the challenges faced by urban transportation networks. With the dramatic increase in vehicle population and the lag in road infrastructure development, cities worldwide are grappling with severe traffic congestion. This congestion not only leads to increased travel times but also contributes significantly to environmental pollution through greenhouse gas emissions (Zhao, J., & Zhou, X.,2019). As a social group-based transport mode, public transport, particularly buses, is seen as an effective method to alleviate congestion and reduce traffic pollution. Buses require less road space per capita compared to private vehicles, and they can transport a larger volume of passengers with higher efficiency. Therefore, enhancing the operational efficiency of buses through prioritization measures is pivotal in addressing urban traffic challenges (Zhai, X., Guo, F., & Krishnan, R., 2023).

The concept of bus prioritization is not new; it has evolved over the years with advancements in traffic engineering and urban planning. Historically, the approach to bus prioritization was straightforward – dedicating specific lanes for buses and adjusting traffic signal timings to favor bus movements. However, as urban traffic conditions became more complex, the need for more sophisticated bus prioritization techniques became evident (Zhao, J., Yu, J., Xia, X., Ye, J., & Yuan, Y., 2019). Today, bus prioritization encompasses a range of strategies, from physical infrastructure changes like exclusive bus lanes to advanced traffic signal control systems that dynamically respond to bus transit needs (Zhao, J., & Zhou, X., 2019).

Bus prioritization directly impacts urban mobility by improving the reliability and efficiency of public transport (Wahlstedt, J., 2011). By reducing delays at intersections and along routes, buses can maintain more consistent schedules, which is crucial for commuters who rely on timely service. Furthermore, by making bus travel faster and more reliable, bus prioritization can entice commuters to shift from private vehicles to public transport, thus reducing the overall number of vehicles on the road. This shift not only alleviates road congestion but also contributes to environmental sustainability by reducing vehicular emissions. The success of bus prioritization in improving urban mobility hinges on a well-thought-out design that considers the unique characteristics of each urban area, the specific needs of the bus transit system, and the overall traffic flow in the city (Qing-fang, Y., & Biao, Z., 2011).

The implementation of bus prioritization strategies involves a multifaceted approach that includes both infrastructure and operational changes. One common strategy is the designation of exclusive bus lanes. These lanes are reserved solely for buses, allowing them to bypass traffic congestion, particularly in high-density urban corridors. The effectiveness of exclusive bus lanes is evident in their ability to reduce delays and improve the punctuality of bus services (Qing-fang & Biao, Year Needed). Another critical strategy is Transit Signal Priority (TSP), which involves modifying traffic signals to extend green phases or reduce red phases when buses are present (Halbach et al., 2022).

TSP strategies can be passive, active, or real-time, depending on the specific operational needs of the bus system. Passive priority strategies operate continuously, regardless of whether buses are present, while active strategies only prioritize specific transit vehicles upon request. Real-time TSP strategies optimize signal timings with the consideration of performance criteria such as person delay, transit delay, and vehicle delay (Zhai, Guo, & Krishnan, 2023).

While the benefits of bus prioritization are clear, implementing these strategies is not without challenges. One of the main challenges is the potential negative impact on other traffic movements, especially at intersections where bus priority measures might disrupt the flow of other vehicles (Gross, Lyon, Persaud, & Srinivasan, 2013). Therefore, careful planning and design are required to ensure that bus prioritization contributes to the overall efficiency of the transportation network without significantly disadvantaging other road users (Saccomanno, Cunto, Guido, & Vitale, 2008). Additionally, the success of bus prioritization depends on several factors, including the existing urban infrastructure, the volume of bus traffic, and the behaviour of other traffic participants. In designing bus prioritization strategies, transportation planners must consider these factors to create an optimized and balanced traffic system (Khwais & Haddad, 2017).

Bus prioritization is an innovative approach in urban traffic management, aimed at enhancing the efficiency and effectiveness of bus services within congested city environments. This methodology employs a diverse array of techniques and technologies, each crafted to optimize bus transit and more seamlessly integrate it into the urban transportation network. Its primary goal is to improve bus travel times, reliability, and overall service quality, thus encouraging a shift from private vehicles to public transportation. The subsequent sections explore the myriad of techniques and technologies utilized in bus prioritization, shedding light on their functionalities, benefits, and considerations for implementation (Furth & Muller, 2000; Kakooza, Luboobi, & Mugisha, 2005).

A cornerstone of bus prioritization is the implementation of exclusive bus lanes. These lanes provide buses with a segregated roadway, free from the typical congestion encountered in mixed-traffic lanes, allowing for consistent speeds and more reliable schedule adherence. The design of these lanes varies, including configurations such as center, offset, curb side, and contraflow lanes, each tailored to specific urban layouts and traffic conditions. Center transit lanes, located in the middle of roadways, are especially effective in urban areas with frequent bus services, as they reduce conflicts with turning vehicles and blockages by parked or stopped vehicles, and are often paired with specialized boarding platforms for efficient passenger transitions (Zhao & Zhou, Year Needed). Meanwhile, offset lanes, positioned between curb side parking and general traffic lanes, balance accessibility and traffic flow. In contrast, curb side lanes, situated adjacent to sidewalks, offer easy access but are more susceptible to obstructions from parked vehicles and loading activities (Zhao, Yu, Xia, Ye, & Yuan, 2019).

Transit Signal Priority (TSP) forms another vital aspect of bus prioritization, enhancing the efficiency of intersections for buses. TSP adjusts traffic signal phases to minimize delays for buses, employing various strategies such as passive, active, and real-time approaches. Passive strategies, which operate continuously irrespective of real-time bus presence, are common in areas with frequent bus services (Guler, Gayah, & Menéndez, 2016). Active strategies, conversely, are activated by transit vehicles on-demand, offering a more targeted and efficient approach. The most advanced, real-time TSP strategies, leverage real-time data on traffic conditions and bus locations to dynamically optimize signal timings, considering factors like transit delay and overall intersection efficiency (Wahlstedt, Year Needed).

An innovative concept in bus prioritization is the Dynamic Exclusive Bus Lane (DBL) design. This approach allows for multipurpose use of the exclusive bus lane at intersection exits, including facilitating left-turn movements of buses. This design enhances the running efficiency of left-turn buses, optimizes lane utilization, and alleviates traffic demand on normal lanes. The DBL design synergistically integrates lane markings, signal timings, and median opening locations to minimize person delay and maximize the efficiency of both buses and private vehicles (Gu et al., 2021).

Sweden's approach to bus prioritization stands as a hallmark of success in the realm of public transportation. The country's initiatives in optimizing bus transit, particularly in cities like Stockholm, demonstrate the effective implementation of bus prioritization techniques and technologies. These examples not only highlight the practicality of such strategies but also their positive impact on overall traffic management and public transit efficiency. Stockholm, the capital city of Sweden, has been at the forefront of implementing bus prioritization strategies. One notable example is the use of the PRIBUSS (Prioritizing of Busses in Coordinated Signal systems) method. This method, standard in Sweden, is a comprehensive approach to bus prioritization in coordinated traffic signal systems. The PRIBUSS method is designed to enhance bus movement through intersections by modifying traffic signal timings to favour bus transit. Research and studies conducted in Stockholm using this method have shown considerable benefits for bus passengers, including significant reductions in travel times (Wahlstedt, 2011). These benefits are achieved with minimal negative impacts on other traffic, highlighting the effectiveness of carefully planned and implemented bus prioritization strategies.

Looking ahead, the future of bus prioritization lies in the integration of advanced technologies and data-driven approaches. With the advent of intelligent transportation systems, there is potential for more dynamic and responsive bus prioritization strategies. For instance, real-time data on traffic conditions and bus locations can be used to adjust traffic signals more effectively, ensuring optimal flow for buses while minimizing disruption to other traffic (Xiaoguang, 2010). Additionally, the use of simulation tools and predictive analytics can aid in the design and evaluation of bus prioritization measures, allowing for more informed decision-making and effective implementation (Saccomanno, Cunto, Guido, & Vitale, 2008). As urban areas continue to grow and evolve, bus prioritization will remain a key component of sustainable and efficient urban transportation planning. The deployment of automated and connected vehicle technology, including the prioritization of automated shuttles in V2X public transport systems, is an emerging field that demonstrates significant potential for enhancing the effectiveness of bus prioritization strategies (Halbach et al., 2022). Furthermore, the exploration of online optimal bus signal priority strategies to equalize headway in real-time exemplifies the ongoing advancements in this area, aiming to balance the needs of buses with overall traffic efficiency (Zhai, Guo, & Krishnan, 2023). These innovative approaches signify a move towards more adaptable and intelligent urban traffic systems, where bus prioritization not only improves the efficiency of public transport but also contributes to the holistic management of urban mobility.

3.4 Challenges in Intersection Design

The design and management of road intersections are pivotal in urban planning and traffic engineering, representing a nexus of various challenging elements that directly influence traffic flow efficiency, road safety, and urban mobility. The complexity of intersection design is notably pronounced in managing diverse and often conflicting traffic flows. According to Hwan NamGung et al. (2020), the simultaneous movement of different modes of transportation – motor vehicles, pedestrians, and bicycles – creates a dynamic environment where safety hazards and operational inefficiencies are prevalent. These challenges necessitate the implementation of multifaceted strategies, such as the segregation of traffic modes through dedicated lanes and signal phases, to ensure the safety and smooth flow of all users.

Intersections present unique safety challenges due to the convergence of different traffic movements. The design and operation of these intersections, whether signalized or non-signalized, significantly influence the occurrence and severity of accidents. A seminal study by Retting et al. (2002) demonstrated that converting traditional intersections to roundabouts in the United States led to a marked reduction in injury crashes, emphasizing the safety benefits of certain design choices. In contrast, signalized intersections, while effective in managing traffic flow, have been associated with a higher incidence of certain types of collisions, such as rear-end crashes, as highlighted by Bonneson and Zimmerman (2004). These findings underscore the need for careful consideration of safety aspects in intersection design, balancing the advantages and risks of different configurations. In urban settings, particularly in densely populated areas, 4-leg intersections present additional layers of complexity. Saeed et al. (2023) highlights the exacerbation of congestion and the heightened risk of accidents in these environments, primarily due to high traffic volumes and the intricate interaction of diverse traffic movements. This congestion not only impacts travel time and fuel consumption but also contributes to environmental degradation through increased vehicle emissions. Addressing these challenges requires a comprehensive approach that includes optimizing traffic signal timing, utilizing intelligent traffic management systems, and redesigning intersections to improve traffic flow efficiency. For example, the introduction of dedicated turning lanes and advanced signaling systems can significantly reduce traffic bottlenecks and enhance safety.

The study by Pan et al. (2021) delves into the realm of unconventional intersection designs, such as Continuous Flow Intersections (CFIs) and Parallel Flow Intersections (PFIs), which are increasingly being considered in areas plagued by heavy traffic. These designs represent innovative solutions to traditional traffic flow problems by altering standard traffic signal phases and patterns, thus facilitating smoother vehicle movements, and reducing overall congestion. However, the implementation of such unconventional designs demands an in-depth understanding of traffic dynamics, as well as a careful consideration of the impact on all road users, including pedestrians and cyclists. The study emphasizes the importance of designs that minimize conflict points and integrate advanced traffic signal systems capable of adapting to real-time conditions, thereby enhancing the safety and efficiency of these complex intersections.

Beyond the immediate challenges of traffic flow and safety, intersection design in the modern urban landscape must also adapt to rapid technological advancements. The integration of intelligent transportation systems, autonomous vehicles, and smart city infrastructure requires a forward-thinking approach that anticipates future developments. This involves the incorporation of sensors, smart traffic signals, and data analytics into intersection design, allowing for dynamic traffic management and improved safety. However, these technological integrations also pose challenges in terms of cost, maintenance, and ensuring compatibility with existing infrastructure.

Intersection design also has profound environmental and societal implications. Non-signalized intersections, for example, can contribute to reduced vehicle idling, thereby mitigating air and noise pollution – a concern highlighted by Wigan (2006) in his analysis of urban traffic impacts. Additionally, the integration of pedestrian and cyclist needs in intersection design is a critical challenge. The work of Zegeer et al. (2002) emphasizes the importance of designing intersections that are safe and accessible for non-motorized road users, a crucial aspect often overlooked in traditional intersection design. Moreover, as urban areas continue to grapple with issues such as air pollution and noise pollution, intersection designs must contribute to environmental sustainability. This includes promoting non-motorized transportation, implementing green traffic signal timing strategies to reduce idling and emissions, and incorporating green spaces within intersection designs to aid in urban cooling and provide aesthetic benefits. The research by Pan et al. (2021) underscores the need for traffic simulation models to evaluate the environmental impacts of different intersection designs, ensuring that they not only address immediate traffic concerns but also contribute positively to the broader urban environment.

3.5 Case Study Relevance

The comprehensive literature review on signalized and non-signalized intersections has direct relevance to my case study of the two interconnected intersections at Museirondellen in Jönköping, Sweden. This case study presents a unique scenario: one intersection is a signalized roundabout (throughabout) with traffic lights that prioritize buses, and the other is a non-signalized intersection also designed with bus prioritization but poses challenges in terms of its design and drivability. The insights gained from the literature on the evolution and effectiveness of throughabouts provide a valuable context for analysing the signalized intersection at Museirondellen. The study highlights the importance of such designs in managing traffic flow and prioritizing public transport, which is directly applicable to evaluating the success and efficiency of the signalized roundabout in my case study.

On the other hand, the non-signalized intersection at Museirondellen, with its design challenges, resonates with the gaps identified in the literature regarding the safety and functionality of such intersections. The difficulties experienced by drivers at this intersection reflect the need for a more nuanced understanding of intersection design, particularly in how it affects driver behaviour and safety. The literature's focus on public perception and the integration of different modes of transport provides a framework for assessing and potentially reimagining the design of this non-signalized intersection to enhance its usability and safety. Additionally, the case study's emphasis on bus prioritization in both intersections aligns well with the literature's discussion on the importance of public transport efficiency in urban planning. This aspect of the study is crucial for assessing how well the intersections serve public transport needs and the overall traffic management system in Jönköping.

3.6 Research Gap

The literature review has elucidated the dynamics of both signalized and non-signalized intersections, highlighting crucial insights into their design, management, and the specific challenges they present. In examining the Museirondellen and Södra Strandgatan intersections in Jönköping, Sweden, several significant research gaps have been identified that our thesis aims to address include:

1- Integration and Impact of Throughabouts with Bus Prioritization: There is a scarcity of empirical research exploring the combined impact of throughabouts and bus prioritization on traffic flow and public transportation efficiency in urban settings. Our research could investigate how throughabouts, when integrated with bus prioritization systems, influence both public transport dynamics and overall traffic efficiency, particularly in mixed traffic environments.

2- Challenges and Efficacy of Signalized Intersection Designs in Urban Areas: While the literature explores various designs of signalized intersections, there is a limited understanding of their efficacy and challenges in densely populated urban areas. Research is needed to evaluate how different signalized designs, including innovative ones like throughabouts, manage high traffic volumes and complex traffic movements, and their implications for urban traffic congestion and safety.

3- Real-World Application and Public Perception of Throughabouts and Bus Prioritization: There is a need for more case studies that examine the real-world application, effectiveness, and public perception of throughabouts combined with bus prioritization strategies. Such studies would provide insights into the acceptance and operational challenges of these systems, contributing to improved designs and implementation strategies in urban traffic management.

These gaps underscore the importance of our research in contributing to the body of knowledge on effective intersection design and management, particularly in complex urban settings like Jönköping. Addressing these gaps through empirical studies could provide significant benefits in terms of traffic efficiency and safety enhancements.

4 Methodology

In this section of this study, we delineate the systematic procedures and analytical techniques employed to investigate the traffic dynamics at Museirondellen and Södra Strandgatan intersections. This includes a detailed description of the simulation tools and data collection methods used, ensuring replicability and providing a robust framework for evaluating the effectiveness of proposed traffic management strategies.

The adoption of PTV Vissim 2024, a powerful microsimulation tool, enabled an in-depth analysis of traffic behavior, including flow efficiency, safety metrics, and congestion management. This tool was pivotal in modeling urban traffic dynamics and evaluating traffic management strategies. Collectively, these methods underscore a commitment to developing sustainable and efficient traffic solutions for Jönköping, preparing the intersections to meet current demands and future traffic growth. That blend ensures that the designs achieve high standards of precision and functionality. The primary designs were developed using AutoCAD Civil 3D, complemented by Autodesk InfraWorks to enhance visual assessments and environmental impact analyses through dynamic 3D modeling. This facilitated a clearer visualization of traffic movements and pedestrian flows. This methodological framework address the redesign of the Södra Strandgatan intersection and analyze the traffic dynamics at both the Museirondellen and Södra Strandgatan intersections in Jönköping. The methodology synthesizes advanced engineering tools with authoritative guidelines and microsimulation techniques. The methodology adheres to the Trafikverket VGU guidelines, ensuring all design elements meet Swedish national standards for safety, efficiency, and environmental sustainability.

4.1 Simulation Model Development

The refinement of the simulation model began with foundational data provided by Jönköping municipality, including traffic signal timings, detector information, and initial map signal models. These elements formed the basis for subsequent modifications to enhance model accuracy and relevance. A critical aspect of this enhancement was the adjustment of the VISVAP logic, tailored to accurately reflect the specific traffic dynamics at Museirondellen and Södra Strandgatan intersections.

The recalibration process involved meticulous mapping of lane configurations to mirror the actual road layouts. This included a detailed representation of bus lanes, marked distinctly to highlight their role in the traffic system and to facilitate analysis of their impact on overall traffic flow. Bus lane dynamics, such as frequency, dwell times, and interaction with general traffic, were closely simulated to assess their efficiency and priority within the traffic network. Advanced traffic signal algorithms were integrated to mirror real-world timing and operations. These algorithms are based on Vehicle Actuated Programming (VAP) which dynamically adjusts to the changing traffic volumes, ensuring that traffic flows as smoothly as possible. The simulation also extended to pedestrian crossing synchronization with adjacent traffic lights, offering a realistic portrayal of traffic behavior across the entire network. This enhanced simulation model serves as a vital tool in urban planning and traffic optimization efforts in Jönköping, providing a more precise and realistic evaluation of potential traffic management strategies and their impacts.

4.1.1 Advanced Traffic Signal Analysis

In the context of urban traffic management, strategically placed detectors are pivotal for optimizing the flow of vehicles in the area of Musemrondellen and Strangatan area see Figure 9. Here, we explore the justification for the placement of various detectors within a specified signal plan, examining their roles in ensuring efficient traffic control and safety. The location of detectors D 5 and D 6, positioned south of the roundabout to monitor the approaching traffic, is critical. These detectors facilitate the adaptive control of signal 7, allowing it to respond dynamically to traffic volumes. This placement is justified by the need to prevent congestion and streamline the flow of vehicles entering the roundabout, thereby reducing the likelihood of accidents and delays.

Detectors D 7, D 8, and D 9, installed within the southern segment of the roundabout and linked to signal 3, play a significant role in the internal management of the roundabout's traffic dynamics. Their purpose is to directly manage the traffic flow within the roundabout, enhancing the coordination between entering and exiting traffic. This strategic placement is essential for maintaining continuous movement within the roundabout, minimizing stop-and-go traffic, which can lead to inefficiencies and increased collision risks. The placement of detector D 10 adjacent to Smedjan parking house on the east side serves to regulate traffic related to entrances and exits from the Smedjan parking house area. Controlling signal 4 based on the real-time data collected by this detector ensures that traffic delays are minimized and that pedestrian safety is prioritized, particularly in areas with potentially high pedestrian activity. Detector D2, situated west of Smedjan parking house, is strategically placed to manage the flow of traffic that interacts with entrances, exits, and possibly parking access points associated with Smedjan parking house. This detector’s role in controlling signal 1 is crucial for facilitating smooth transitions onto main roads, thereby avoiding back-ups that could extend onto busier arteries.

The positioning of detector D 3 inside the roundabout, tasked with monitoring and managing the traffic exiting the roundabout, is justified by the need to enhance traffic decongestion efforts post-roundabout navigation. By controlling signals 6 and 5, this detector ensures that traffic is efficiently distributed onto subsequent roads, thereby reducing potential bottlenecks. Lastly, detector D 4’s location south of the roundabout and its association with signal 8 highlight its role in managing downstream traffic flows. This strategic placement aids in the smooth merging and transitioning of vehicles from the roundabout to southern routes, crucial for preventing traffic accumulation and facilitating a steady flow of vehicles.

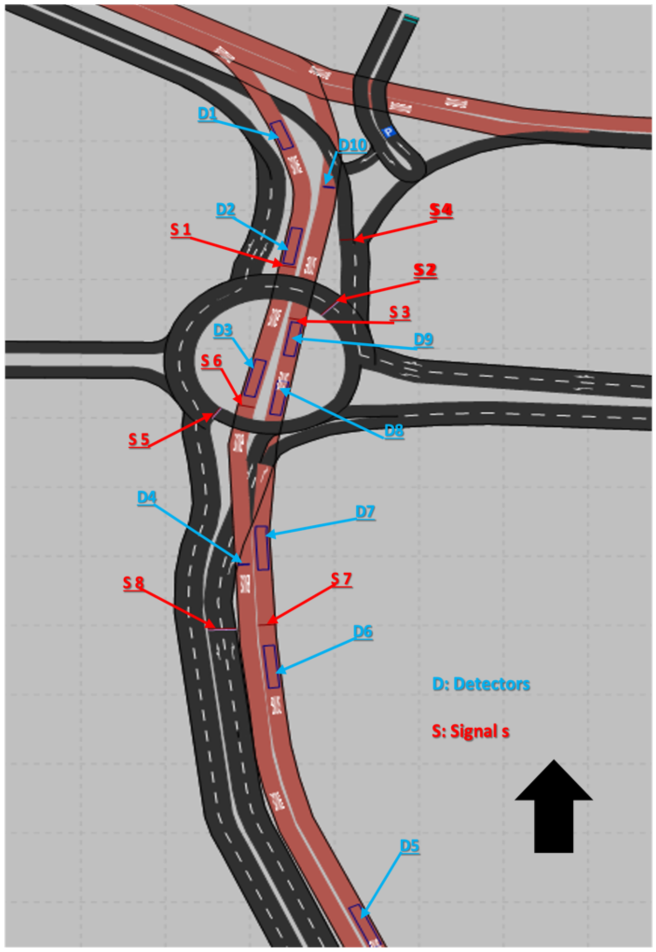

Figure 9: Detailed signal plan

4.1.2 Visvap flow chart

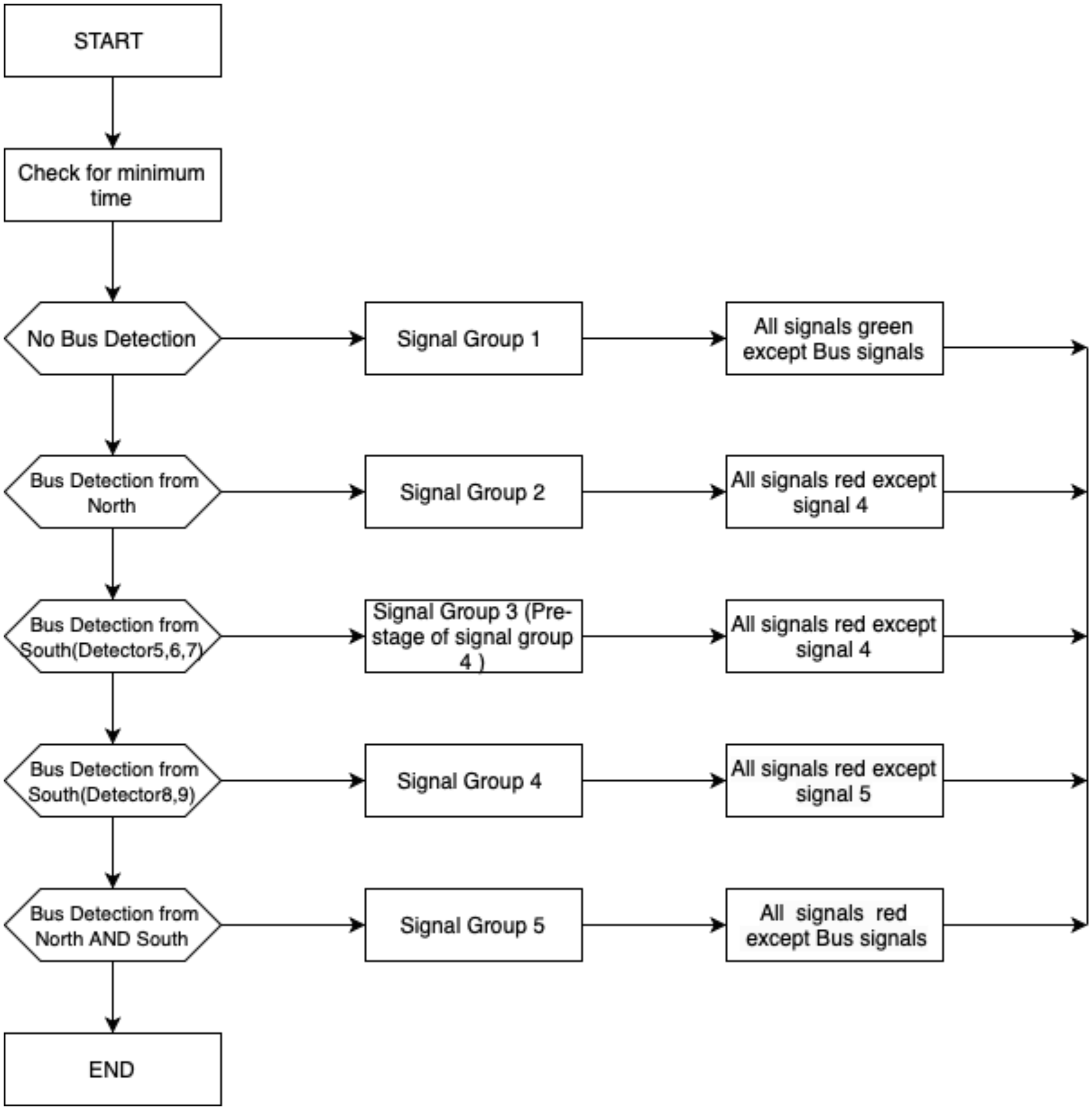

Figure 10: Simplified version of a more complex VISVAP chart

The flowchart presented in Figure 10 is a simplified version of a more complex VISVAP chart, designed to provide a clearer and more straightforward explanation of the traffic signal control system based on bus detection. It outlines the fundamental steps and signal groups involved in managing traffic lights at intersections, focusing on optimizing traffic flow and prioritizing bus movements. The process initiates with a "Check for Detectors" phase, where the system scans for the presence of buses using specialized detectors. If no buses are detected during this initial check, the system defaults to Signal Group 1, where all signals for cars are set to green. This allows for normal traffic flow until a bus is detected. If a bus is subsequently detected from the north, the control system transitions to Signal Group2. In this scenario, all signals for cars turn red, except for car signal number 4, which remains green to allow cars from specific directions to proceed. This setup minimizes the disruption to overall traffic flow while giving priority to the northbound bus. The system continuously monitors for further bus detections. If a southbound bus is detected during this phase, the system then shifts to Signal Group 3. If buses from both directions are detected, it advances to Signal Group 5.

Signal Group 3 is specifically for handling a bus detected from the south. Similar to Signal Group 2, it turns all car signals red except for car signal number 4. The continuation into Signal Group 4 occurs if further detection from the south is noted, with the system maintaining the green signal for car number 4 unless a bus is also detected by detector 10, which would cause all signals to turn red. Signal Group 5 is a critical phase where buses from both directions have been detected. In this state, all car signals are turned red to completely halt vehicle traffic, allowing buses free passage from both directions. The system remains in this mode until no further buses are detected, at which point it resets to the initial detection phase.

Overall, this flowchart illustrates a responsive and adaptive traffic management system designed to prioritize bus traffic at busy intersections while balancing the needs of regular vehicular flow. The system's ability to adjust based on bus detection and directionality ensures that traffic disruption is minimized, and safety is maintained. For the interest in a more detailed and technical depiction of this traffic management system, the complete VISVAP chart done by us based on the provided data such as the detector data, signal plan and signal data that are provided from Jönkoping muncipality refer to the appendix B.

4.2 Survey

To enhance road safety and optimize traffic flow, a detailed survey was conducted targeting drivers navigating the intersections at Museirondellen and Södra Strandgatan. This area, known for its complex traffic patterns, has been a focal point of concern for both city planners and daily commuters. The objective of the survey was to gather firsthand information from drivers to better understand their experiences, perceptions, and suggestions for improvements. Google Forms was used to facilitate data collection in this survey and the following link refers to the conducted survey (https://forms.gle/vDMsd2c97ZwQgiGU7).

The survey encompasses a range of questions designed to delve into various aspects of driving experience in this specific area. These aspects include the frequency of drivers' use of these intersections, their experiences of confusion or clarity while navigating, their perception of safety, and incidents of misrouting. Additionally, the survey aims to evaluate the ease of accessing key locations such as Parkeringshus Smedjan, the effectiveness of current road designs, and the potential benefits of proposed changes such as redesigning the intersections or improving signage.

Drivers' input on these matters is crucial for developing a data-driven approach to enhancing road safety and efficiency. The responses will provide valuable insights into current issues and will be instrumental in guiding future urban planning and traffic management decisions in the area. Below in Table 1 is a structured summary of the survey questions, outlining the key topics and the specific areas each question addresses:

Table 1: Summary of the survey questions

Question	Description
Frequency of Using the Area	How often drivers travel through Museirondellen and Södra Strandgatan: daily, several times a week, occasionally, or rarely.
Experience of Confusion	Frequency of feeling confused while driving through the area: often, sometimes, or never.
Perception of Safety	Drivers' sense of safety in the area, ranging from completely safe to very unsafe.
Incidents of Wrong Routing	Whether drivers have mistakenly taken the wrong route in the area.
Ease of Navigating to Parkeringshus Smedjan.	How easy or difficult drivers find navigating to Parkeringshus Smedjan for parking.
Clarity and Safety of Road Design	Rating of the road design at Museirondellen and Södra Strandgatan from very clear and safe to extremely confusing and unsafe.
Benefits of Redesigning for Safety	Opinions on whether redesigning the intersections would improve safety.
Impact of Better Signage	Whether improved signage could make driving in the area easier and safer.
Suggestions for Improvements in Södra Strandgatan	Suggestions for changes in Södra Strandgatan, including redesign, area improvements, enhancing signage and road markings, or maintaining current design.
Need for Changes in Geometric Designs	If altering the geometric designs of Museirondellen and Södra Strandgatan would improve traffic flow and safety.

The survey responses will play a crucial role in shaping the proposed solutions for the intersections at Museirondellen and Södra Strandgatan. By analyzing drivers' experiences and perceptions, we aim to pinpoint specific areas for improvement, whether in design, signage, or signal optimization. This feedback, when combined with the data from traffic simulations, will guide us in identifying key focus areas for our proposed changes. For instance, if a significant number of drivers report confusion at certain points, this could indicate a need for clearer signage or re-evaluation of the current geometric design. Similarly, concerns about safety or frequent wrong routings might suggest the need for modifications in traffic signal timings or lane arrangements. This comprehensive approach ensures that our proposed solutions are not just technically sound but also address real-world challenges faced by drivers, leading to more effective traffic management.

5 Results

This section provides a thorough analysis of our network infrastructure's current performance by exploring individual link segments and node output capacities. Utilizing a blend of recent survey findings and simulation results, we aim to identify critical bottlenecks and pinpoint areas where traffic congestion is notably severe. This detailed evaluation serves as a foundational step in planning enhancements and ensuring the reliability and scalability of our infrastructure to meet future demands.

5.1 Traffic Simulation for Current Situation

This section presents an analysis of traffic patterns based on simulations carried out using the PTV Vissim software, focusing on the average outcomes derived from multiple runs. These simulations, conducted ten times each for an hour, were initiated from the 900-second mark to the 4500-second mark of the total 3600 seconds, avoiding the initial and final fluctuating conditions to ensure the stability of traffic flow. The results are represented as average visualizations from these runs, providing insights into vehicle speeds, densities at a complex junction, and queue lengths along critical stretches of the road network. The analysis is divided into two distinct parts: the first part discusses the link segment results, which include metrics such as density, speed, and queue length. The second part delves deeper into the node results for the artery road, examining more intricate aspects of traffic flow and interactions at key intersections. This structured approach allows for a comprehensive understanding of both the general traffic behavior along the links and the specific dynamics at the nodes.

5.1.1 Speed Link Segment

Figure 11 is a representation from a traffic simulation model, which illustrates the average speeds on different links of a road network that appears to be a complex junction or interchange.

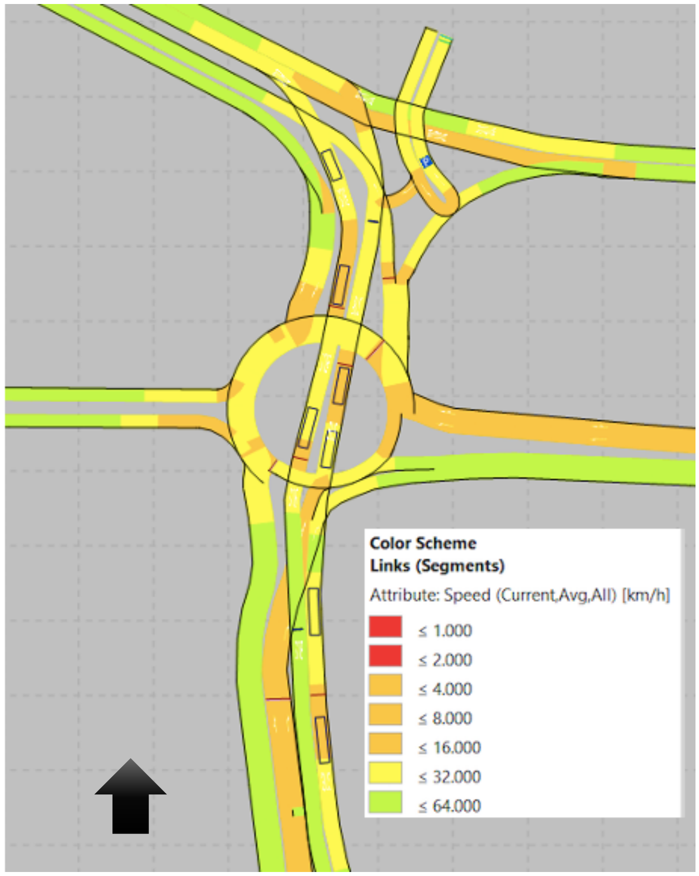

Figure 11: Current visualization speed

The color scheme employed in the figure serves as an indicator of the traffic speeds, with a range starting from red, representing the lowest speed areas, to dark green, signifying the parts of the network where traffic moves at higher speeds. Upon analyzing the figure, it is observed that the segments running from north to south (Södra Strandgatan to Östra Strandgatan) are predominantly marked in green, which indicates that vehicles traveling in these directions tend to maintain a higher speed, suggesting a smoother traffic flow. In contrast, there are segments, possibly oriented east to west (towards Odengatan), that show yellow and orange color, signifying a reduction in speed. This pattern of speed reduction could be due to several factors such as the physical design of the road, traffic density, and intersections that require vehicles to decelerate. The red segments, which reflect the slowest speeds, are crucial for detailed examination as they may highlight congestion points or bottlenecks within the interchange. These areas could be experiencing low speeds due to high traffic volumes, traffic control signals, or due to the merging and diverging maneuvers that typically occur at such junctions. The transitional areas from red through to green—where speeds are seen to incrementally increase—illustrate the zones where traffic begins to disperse and accelerate, possibly after passing through the congestion or a traffic control device.

5.1.2 Density Link Segment

In Figure 12, different colors show how dense the traffic is on various parts of the interchangeroads where vehicles merge, diverge, and cross paths.

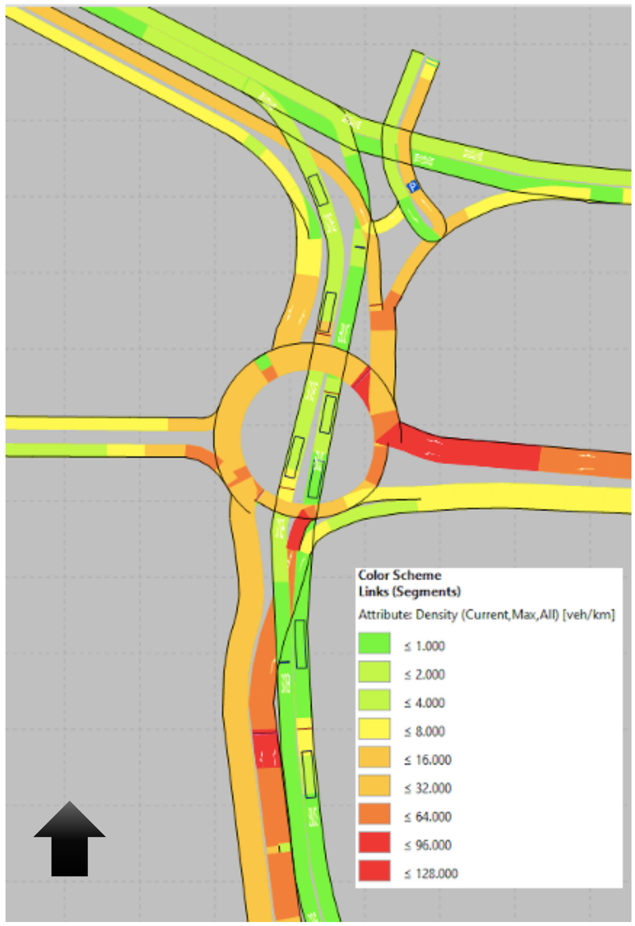

Figure 12: Current visualization density

Light green indicates areas with the least traffic, suggesting that vehicles are likely moving freely at the posted speed limits. These low-density areas are what we aim for in traffic planning because they mean roads are being used efficiently and safely. As colors shift from light green to yellow and then to red, they show where traffic gets heavier. Yellow hints at more cars on the road, but they're likely still moving at reasonable speeds. However, where the map turns red, traffic density is high and there are more vehicles than the road can handle comfortably, leading to slower speeds. The darkest red areas East Road (Odengatan) are of particular concern as they signal congestion, where traffic could be stop-and-go or even at a standstill.

Upon closer inspection, the highest traffic density appears to be concentrated around the parts of the interchange where vehicles are joining or leaving the main flow. These are challenging spots in any road system because vehicles are changing lanes and speeds, which naturally leads to more congestion. It's common for these areas to require careful analysis and targeted solutions to improve traffic conditions. In professional traffic analysis, understanding where and why congestion occurs is crucial. This simulation helps to do that by highlighting problem areas. For example, if the map shows consistently high density from the north, thus it might conclude there's a heavy inflow of traffic from that direction. If it's lighter from the south, this could mean fewer vehicles are entering the interchange from there, or the design allows for smoother merging. In essence, this Figure 12 .gives us a clear picture of which parts of the interchange are working well (the green areas) and which parts are not (the red areas). This kind of analysis is a vital step in creating road systems that serve the needs of drivers, improve safety, and keep traffic flowing, which is the ultimate goal of traffic engineering.

5.1.3 Queuing Length Link Segment

Figure 13 shows the analysis of queue lengths at key arterial roads within the simulation model indicates significant congestion issues that can be attributed to suboptimal geometric designs.

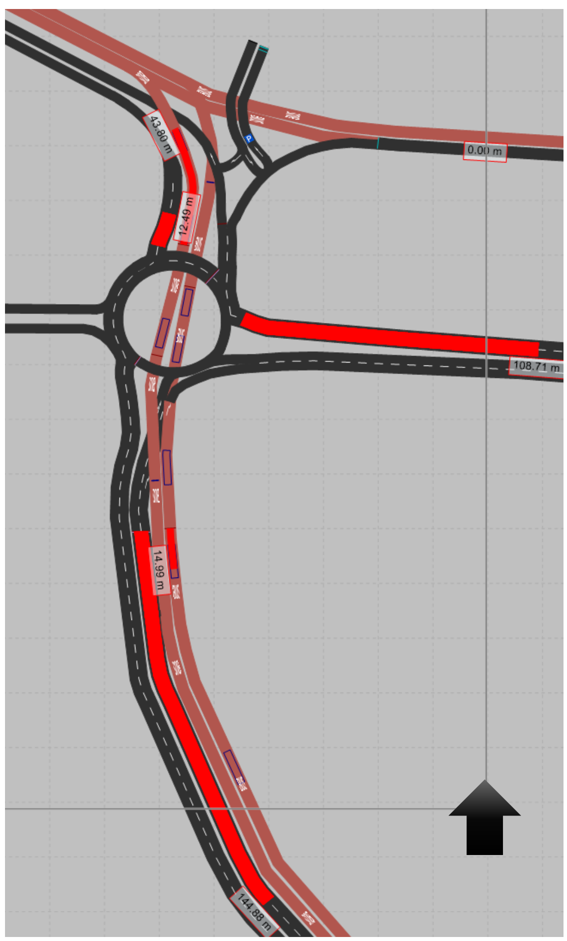

Figure 13: Current visualization queue length

Specifically, the data reveals a queue length of 108.71 at East Road (Odengatan) and 144.88 at South Road (Östra Strängatan), suggesting excessive vehicle accumulation due to inadequate road geometries. The Factor of a poorly designed intersections may be contributing to these bottlenecks.

5.1.4 Node Data Analysis

The traffic simulation has highlighted significant issues within our system, particularly in terms of extensive queuing and delays. These challenges are evident during peak traffic periods and suggest inefficiencies in the current traffic light configurations and overall traffic management. As part of our approach to addressing these problems, we conducted simulations under three scenarios with incremental increases in traffic data of three arterial roads, enhancing the traffic volume by 10%, 15%, and 20% respectively. This detailed investigation of the node results will allow us to understand the specific contributions of each intersection and junction to the overall traffic dynamics and identify targeted solutions to improve the system's efficiency.

5.1.4.1 Östra Strandgatan

The traffic data for östra strangatan shown in Figure 14 provides an illustrative look at how increasing traffic volumes contribute to congestion along this specific lane.

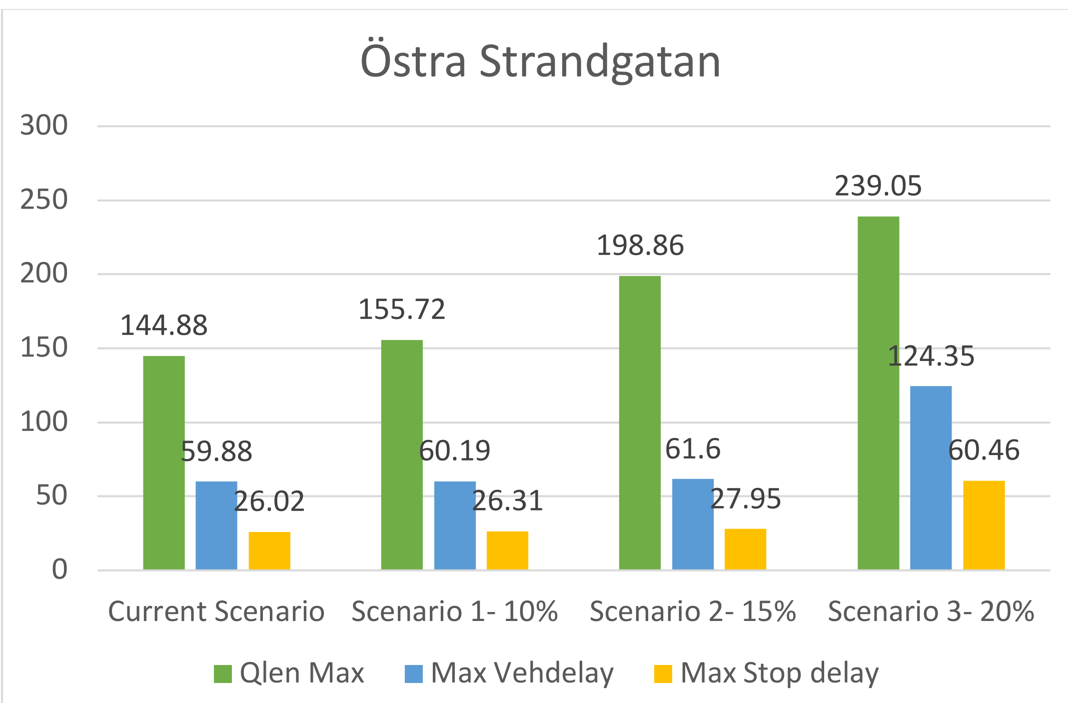

Figure 14: Node results for 3 scenarios at Östra Strandgatan

The maximum queue length (QLENMAX) exhibits a consistent growth through the scenarios. Starting at 144.88 vehicles in the current scenario, it stretches to 155.72 vehicles in Scenario 1 and further to 198.86 vehicles in Scenario 2. The trend continues, peaking at 239.05 vehicles in Scenario 3, which underscores the lane's limitations in coping with high traffic volumes.Regarding delays, the maximum vehicle delay (Max VEHDELAY) initially shows a minimal increase from the current scenario's 59.88 seconds to 60.19 seconds in Scenario 1. However, as traffic volume continues to rise, we witness a more notable delay of 61.6 seconds in Scenario 2. The delay reaches its apex in Scenario 3, with a staggering 124.35 seconds, more than doubling the initial figure and indicating severe congestion.The maximum stop delay also experiences a gradual increase from Scenario 1to 26.31 seconds to Scenario 2 to 27.95 seconds, and then a significant spike in Scenario 3, reaching 60.46 seconds. This indicates that at higher traffic volumes, the duration for which vehicles remain stationary increases dramatically, pointing to substantial congestion at stops, possibly due to oversaturation.In sum, the progression from the current scenario to Scenarios 1, 2, and 3 with respective traffic increases of 10%, 15%, and 20% clearly demonstrates the compounding effect of additional vehicles on congestion levels.

5.1.4.2 Odengatan

The traffic data for Odengatan provided in Figure 15 show a compelling narrative of the impact of increased traffic on congestion within this particular lane.

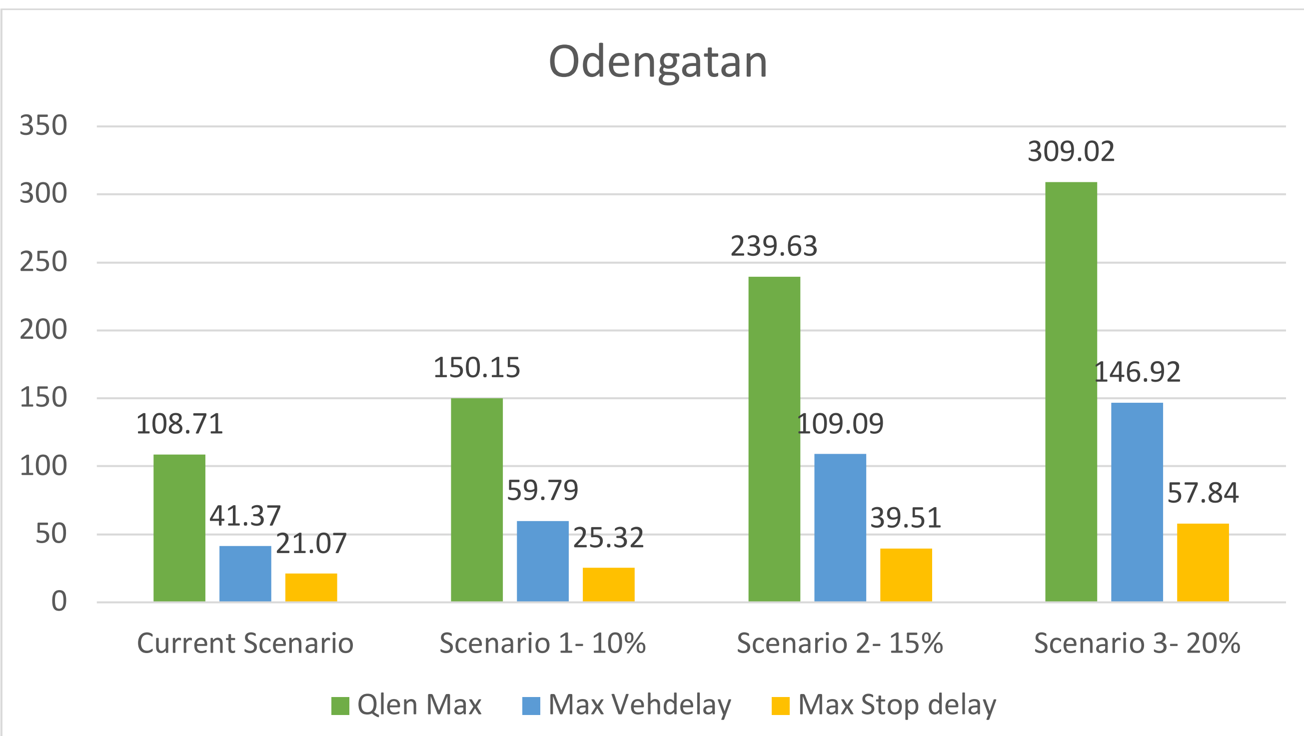

Figure 15: Node results for 3 senarios at Odengatan

For the maximum queue length (QLENMAX), there is a progressive increase across the scenarios. It begins at 108.71 vehicles in the current scenario, advances to 150.15 vehicles in Scenario 1, and then climbs to 239.63 vehicles in Scenario 2. This growth trajectory peaks at 309.02 vehicles in Scenario 3, marking a troubling trend that signifies the lane's substantial struggle to cope with an increasing number of vehicles without succumbing to severe congestion.

Turning to the maximum vehicle delay (Max VEHDELAY), there is an initial increase from 41.37 seconds in the current scenario to 59.79 seconds in Scenario 1. This trend of increasing delays continues, becoming more pronounced with a delay of 109.09 seconds in Scenario 2. The delay escalates further in Scenario 3, reaching 146.92 seconds. This progression indicates that as the volume of traffic increases, the delays encountered by vehicles grow significantly, leading to longer waiting times and a reduced level of service.
Similarly, the maximum stop delay also increases as traffic volumes rise, starting at 21.07 seconds in the current scenario, moving to 25.32 seconds in Scenario 1, escalating to 39.51 seconds in Scenario 2, and finally peaking at 57.84 seconds in Scenario 3. These increments in stop delays reflect the compounding effects of traffic volume on congestion, with each scenario presenting a more challenging environment for traffic flow, resulting in longer and more frequent stops.

5.1.4.3 Södra Strandgatan

The traffic data for Södra strandgatan in Figure 16, which is characteristically a road with low congestion levels, reveals the effects of incremental traffic volume increases on its traffic dynamics.

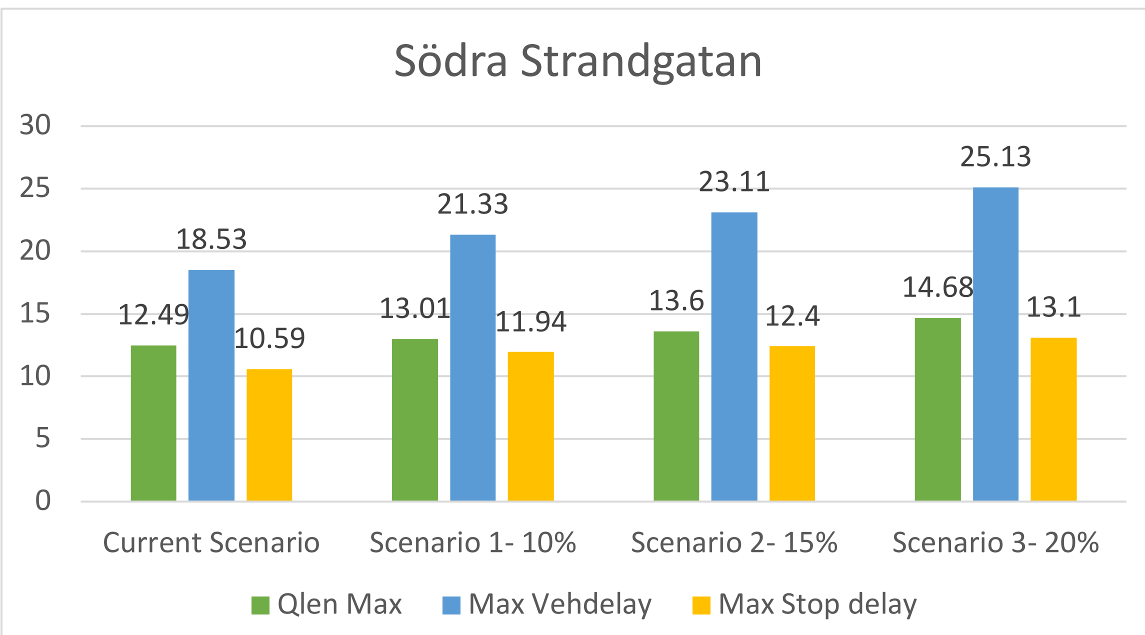

Figure 16: Node results for 3 senarios Södra Strandgatan

The maximum queue length (QLENMAX) shows a similar pattern, beginning at 12.49 vehicles for the current scenario. It climbs gradually to 14.68 vehicles in Scenario 3, suggesting that while the road is well-suited to handle its usual traffic volumes with minimal delay, there is a noticeable though not yet critical rise in the number of vehicles during peak conditions as traffic volumes increase. Maximum vehicle delay (Max VEHDELAY) starts at 18.53 seconds in the current scenario, escalating to 25.13 seconds in Scenario 3. These increases are relatively contained, indicating that even as traffic volume grows, the delays remain within a manageable range for a road not characterized by heavy traffic.The maximum stop delay also sees a steady but unspectacular increase from 10.59 seconds in the current scenario to 13.1 seconds in Scenario 3. This slow growth in delays at stops underscores the fact that Södra strangatan generally remains uncongested, even as it absorbs higher traffic volumes.In summary, the analysis from the current scenario through Scenarios 1, 2, and 3 demonstrates that Södra strangatan, typically free from significant congestion, exhibits only slight increases in queue lengths and delays as traffic volume progressively increases. The data underscores the importance of traffic management to maintain this uncongested state, despite the gradual rise in vehicle numbers.

For a more detailed presentation of the node-specific results derived from the PTV Vissim simulations, please refer to Appendix C. This appendix contains extensive data and analysis concerning the traffic flows and interactions at crucial intersections within the simulation model. It includes tables that provide an in-depth view of variables such queue lengths, max queue length , vehicle delay ,and stop delay. This additional data is critical for understanding the complexities of traffic management and for evaluating potential improvements within the traffic network.

5.2 Survey

To gain deeper insights into the public’s experience with these intersections, a survey was conducted. The survey aimed to ascertain whether drivers indeed find navigating these intersections confusing, as suggested by the media coverage. The responses, which were numerous and varied, provide valuable data for understanding the user experience and safety implications of the intersection design.

5.2.1 Driving Frequency and Experience in the Area

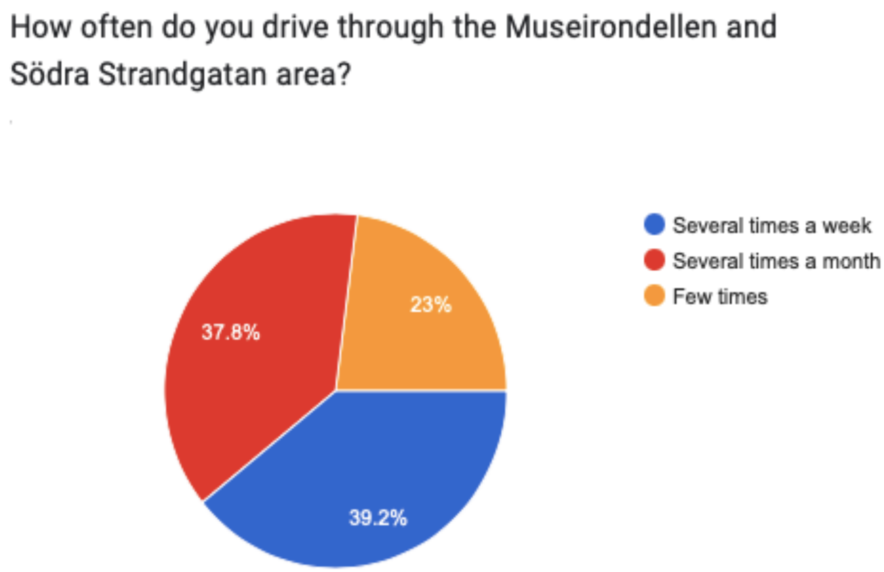

Figure 17: Survey result for Question 1

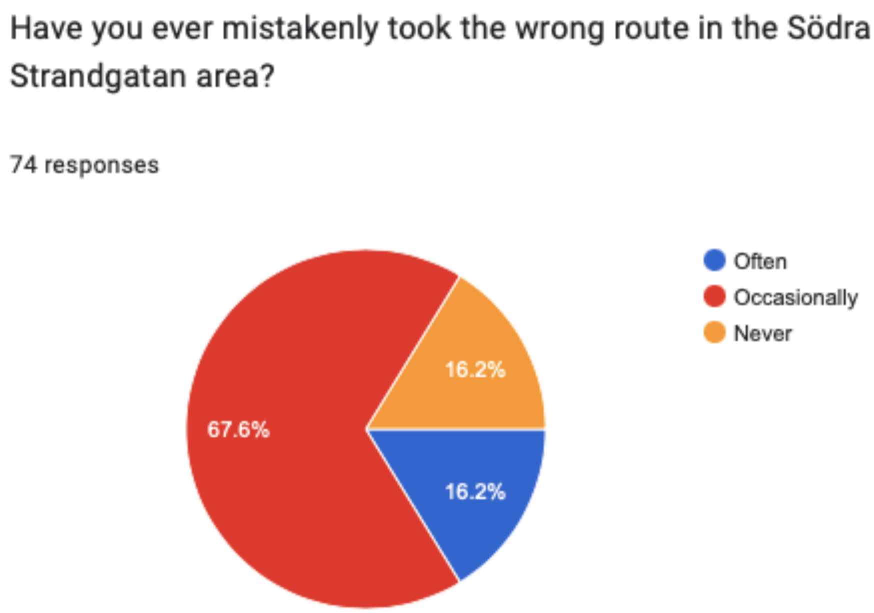

Figure 18: Survey result for Question 2

Figure 18 shows survey results for question 1&2 which demonstrate a significant regular interaction with Museirondellen and Södra Strandgatan, as evidenced by 34.3% of respondents driving through the area several times a week and 41.8% several times a month. This regular use by many drivers means that the roads and signs need to be designed in a way that meets their needs well. In contrast, the high incidence of navigation errors reported by 82.1% of drivers (13.4% frequently and 68.7% occasionally) highlights a disparity between the design of the area and the navigational expectations of its users. This difference is particularly confusing for people who don't drive there often and depend on clear and easy-to-understand directions.

5.2.2 Perception of Safety and Confusion

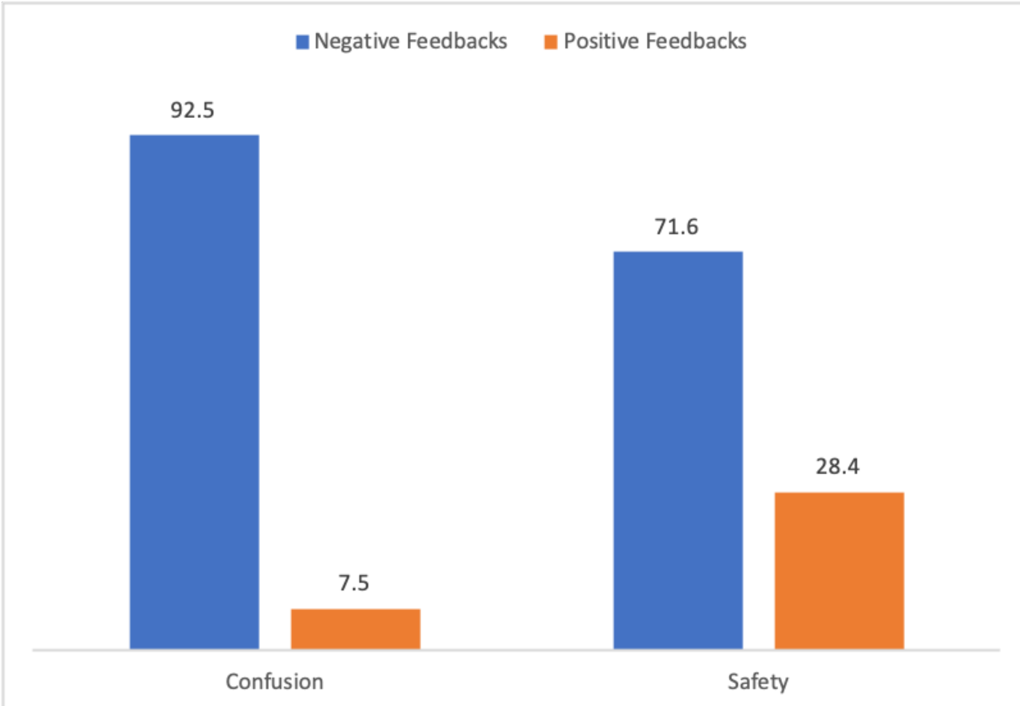

Figure 19: Survey result for questions that covers perception of Safety and Confusion

Figure 19 reveal the data pervasive sense of confusion among drivers, with 90.7% experiencing it to varying degrees (50.7% often, 40.3% sometimes). This confusion, while detrimental, also has broader implications, including potentially hazardous driving conditions due to hesitant or abrupt decisions. Moreover, the reported feelings of unsafety (56.7% somewhat unsafe, 13.4% unsafe) suggest a significant impact on driver psychology and behavior, which is crucial in a domain where confidence and clarity are paramount. Furthermore, 84.8% of respondents consider the road design unsafe and necessitates a redesign of the current infrastructure.

5.2.3 Challenges in Navigation

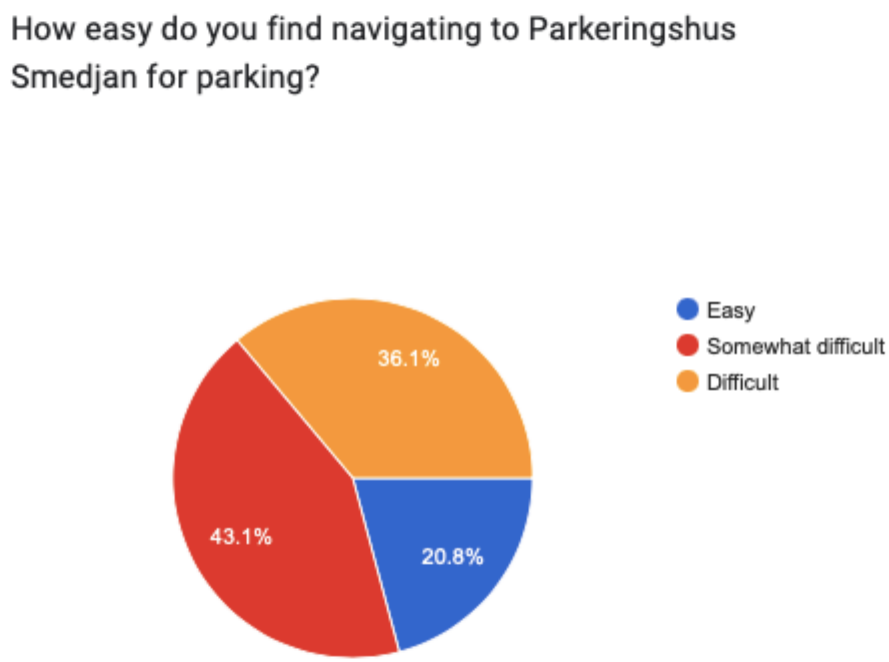

Figure 20: Surcey result for question that cover challenges in navigation

Figure 20 shows difficulties faced by 76.8% of drivers in reaching a critical destination like Parkeringshus Smedjan spotlight severe deficiencies in the area's navigational setup. This struggle is likely due to inadequate signage, overly complex routes, and a lack of intuitive directionality, which not only challenges the drivers but also reduces the ease of access.

5.3 Need for and Type of Improvement

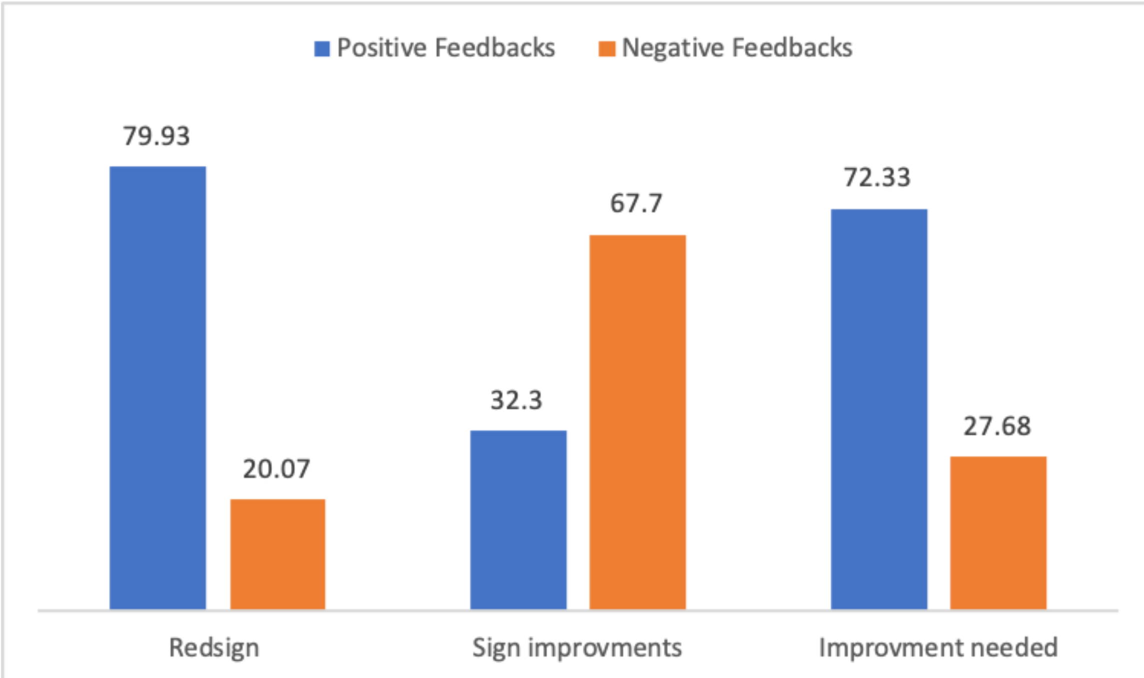

Figure 21: Survey results that cover questions for reflecting on public opinion

Figure 21 reflecting on public opinion, it is evident that 53.7% of respondents see a redesign as a pathway to enhanced safety, indicating a significant dissatisfaction with the current state. The split opinions on signage (39.4% in favor of improvements, 43.9% against) highlight a detailed understanding among the public that while signage is a critical element, it by itself is not a complete solution for the area's wider design problems. The emphatic preference for a comprehensive redesign of Södra Strandgatan (81.8%) and the call for major geometric design changes (62.1%) highlight a general agreement for major and thorough changes.

5.3.1 Analysis

The survey data not only underlines a critical need for redesigning the Museirondellen and Södra Strandgatan area but also specifically accentuates the urgency to focus on Södra Strandgatan. This need arises from a distinct pattern of driver confusion and perceived unsafety, which is more pronounced in Södra Strandgatan than in Museirondellen. In urban transportation, the experiences of people who use these roads frequently should not be neglected. Many drivers express confusion, which goes beyond being a minor inconvenience to a significant problem that influences their sense of safety and ease. Such confusion, particularly highlighted in the Södra Strandgatan area, often leads to confusion and incorrect navigation decisions, complicating the driving experience in an already dynamic urban setting. This is not just about navigating physical spaces but also, it's about handling the mental challenges that arise from confusing and unclear road designs.

The survey shows that many drivers, both those who know the area and newcomers, are confused. This suggests that Södra Strandgatan needs redesign. By making the roads clearer and the signs more straightforward, we can turn driving from a stressful and uncertain experience into one that is clear and confident. A well-designed layout will reduce confusion and make driving safer and easier for everyone. Additionally, the survey hints that the current design of Södra Strandgatan might not only be confusing but also inefficient, leading to many navigation mistakes. A new design focused on simpler routes and clear directions could make traffic flow better. The goal is not just to reach a destination but to do so easily and without stress. Moreover, by focusing on these aspects of redesign, there is an opportunity to enhance the user experience significantly. This is about more than just using the road; it's about making a place where drivers feel sure and comfortable. The current unhappiness of drivers shows a big gap between the road design and what they need. A careful redesign could make their daily travel more enjoyable and less of a hassle.

Thus, based on the survey results a redesign of Södra Strandgatan is required. This redesign should comprehensively tackle the common problems of safety, confusion, and difficulty in navigation. It should aim to make the layout of Södra Strandgatan clearer and more intuitive. By doing this, the redesign won't just make driving better in the short term but also promote a feeling of well-being and confidence in regular users of these roads.

6 A New Design and Control Solution

In response to the survey and simulation results, this section presents a new design for the Södra Strandgatan intersection, aimed at improving safety, clarity, and driving experience, guided by Trafikverket VGU 2022 standards. The redesign includes a detailed simulation analysis to compare current and proposed traffic scenarios. This analysis highlights the new design's effectiveness in enhancing traffic flow, reducing congestion, and improving safety, providing empirical evidence to support the proposed changes.

6.1 New Geometric Design

The redesign as showing in Figure 22.adheres to established standards, primarily following the guidelines from the Trafikverket VGU 2022, which sets forth standards for highway design but also serves as a crucial reference for intersection design. By integrating these authoritative guidelines, the proposed design aims to transform these intersections into more intuitive and user-friendly spaces, thus enhancing safety and reducing driver stress. In, the various elements of the intersection are distinguished by color-coded hatching: the red hatch indicates the bus lanes, the gray hatch outlines the vehicle lanes, and the green hatch signifies the refuges, which are elevated by 10 cm from the curbstone level. Additionally, traffic markings are depicted in black. For further details, refer to Appendix D, which contains the full PDF documentation.

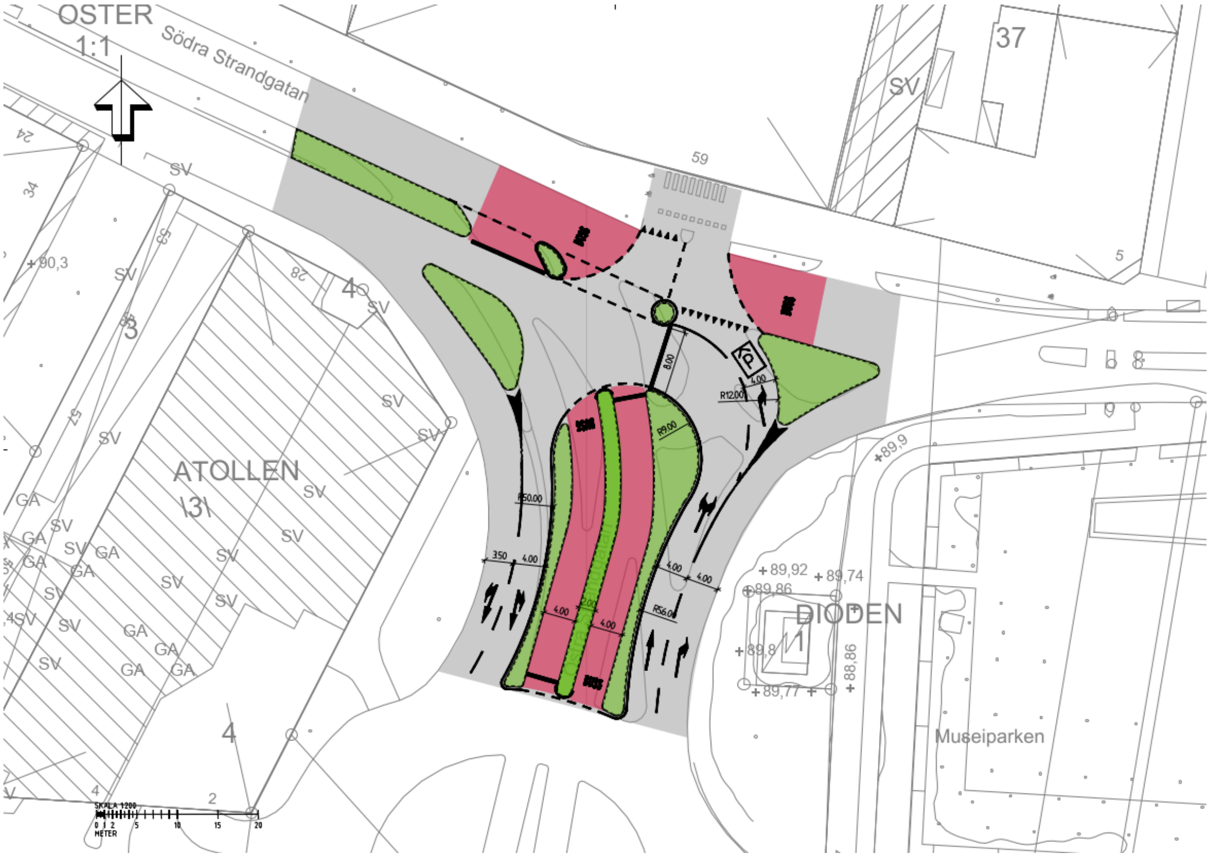

Figure 22: Proposed design drawing

6.1.1 Design Standards and Implementation

Initially, an assessment of the available space was crucial given the intersection's encirclement by buildings, which set the boundaries for the redesign. This intersection, which integrates four streets and includes critical access points such as the Smedjan parking house and multiple bus lanes, presents a unique design challenge due to its proximity to a roundabout and the diversity of vehicular paths intersecting. To address these complexities, the design process began with a review of lane width standards, which depend heavily on traffic speed, volume, and the types of vehicles frequenting the intersection. Particularly, the need to accommodate large delivery trucks (Lps type) see Figure 23, which are prevalent due to nearby commercial establishments, influenced the lane width decisions.

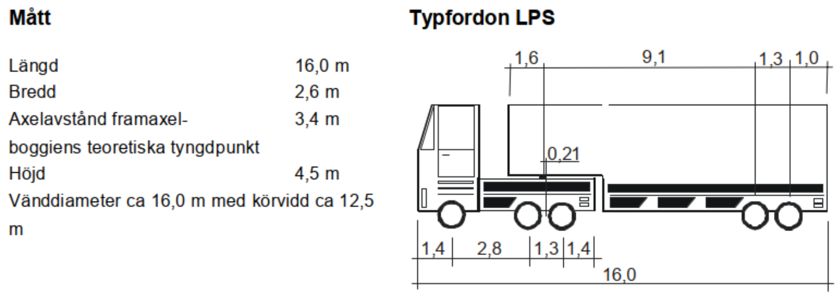

Figure 23: Type of vehicle frequenting the intersections (Trafikverket; RÅD-VGU, 2022)

According to VGU, dimensional needs for vehicles, including intersections and curves, must be carefully evaluated through spatial studies and driving track simulations (Trafikverket, RÅD - VGU, 2022). For the predominant Lps trucks, the lane width was determined to be from 3.25 to 3.5 meters per lane, as specified in the VGU see Figure 24.

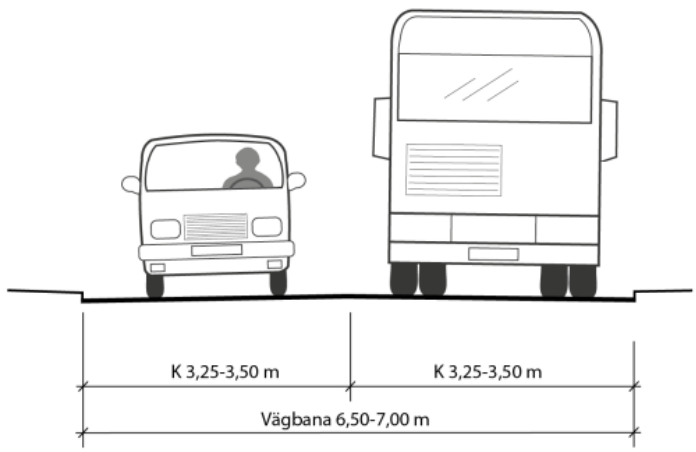

Figure 24: Lane dimension (Trafikverket, RÅD - VGU, 2022)

However, given the curved nature of several lanes in the new design, a width of 4 meters was implemented for four lanes including the lane that led to the parking to facilitate safer and more efficient navigation, while one lane remained at the standard 3.5 meters.

Inspired by the innovative VGU 2022 guidelines, our redesign of the Södra Strandgatan intersection features a novel element: a half-roundabout known as a "drop refuge" (See Figure 25).

Figure 25: Inspired Drop refuge (Trafikverket, KRAV-VGU, 2022)

The addition of the drop refuge optimally fits the existing space and meets the complex traffic demands of the intersection. It significantly reduces conflict points and streamlines vehicular paths, particularly for buses, enhancing both safety and efficiency. This setup ensures that all lanes converge smoothly, facilitating easier navigation and reducing potential bottlenecks. This feature was incorporated to optimize the flow within the constrained space, accommodating all vehicle types, including buses, within the roundabout structure. The design specifies an inner radius (Ri) of 9 meters and an outer radius (Ry) of 17 meters to ensure ample maneuvering space for the Lps vehicles. This configuration allows for a lane width within the roundabout of 8 meters, aligning with VGU standards (See Figure 26 for Ri &Ry, roundabout dimensions).

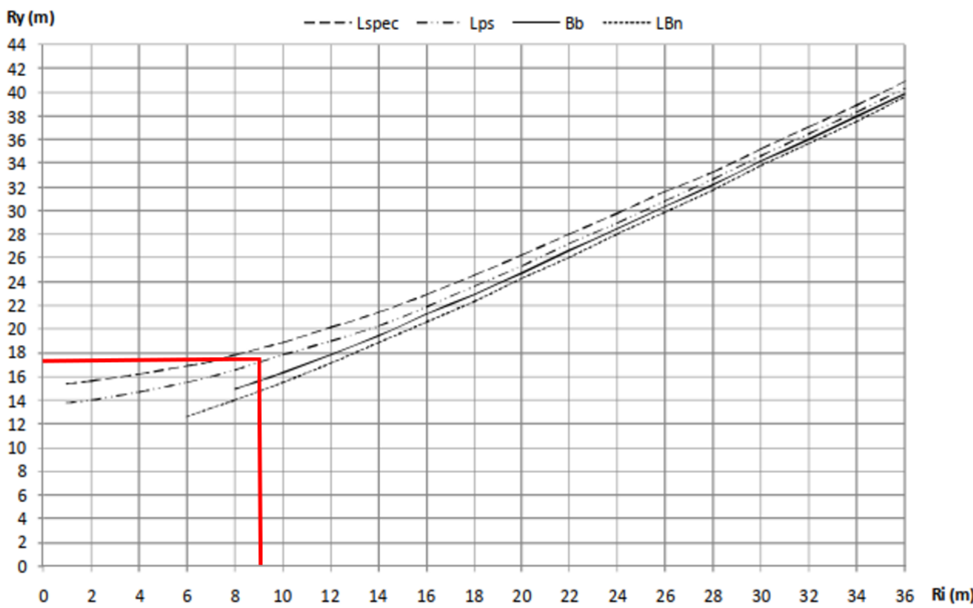

Figure 26: Ri &Ry, roundabout dimensions (Trafikverket, KRAV-VGU, 2022)

By integrating these elements, the redesigned intersection not only adheres to the highest standards of road safety and efficiency as outlined by VGU 2022, but also improves the navigational clarity and safety for all intersection users.

6.1.2 3D Visualization

The redesign of the intersection at Södra Strandgatan has been meticulously visualized using advanced 3D modeling capabilities provided by Autodesk InfraWorks. This technology facilitated a dynamic representation of the intersection, enabling a comprehensive analysis of spatial dynamics, traffic patterns, and the incorporation of novel design elements into the existing urban landscape. The 3D models feature realistic textures, lighting, and environmental factors, enhancing the evaluation of both aesthetic and functional aspects of the design. The included Figure 27, and Figure 28, offer an aerial perspective of the entire intersection, illustrating the innovative design from various viewpoints.

Figure 27: Infraworks visualization from south to north view

Figure 28: Infraworks visualization from north to south view

6.1.3 Comparative Analysis

The comparison of the existing and revised designs of the Södra Strandgatan intersection highlights key enhancements to accessibility, traffic flow, and safety. The redesign simplifies entry and exit points, integrates traffic lights for clear bus lane prioritization, and repositions traffic lights to optimize queuing space and reduce congestion. The Figure 29 and Figure 30 illustrate the differences between the existing and new design of the intersection.

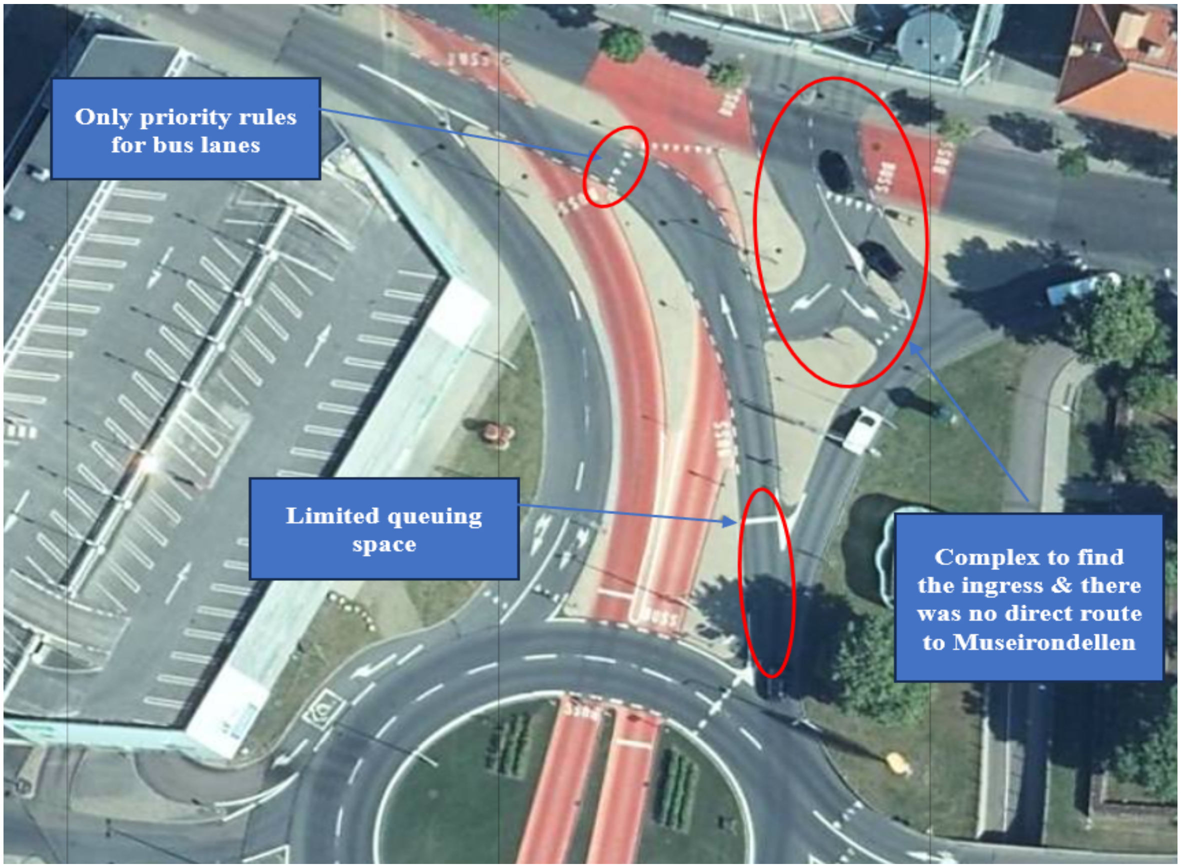

Figure 29: The existing design of the Södra Strandgatan intersection

Figure 30: The New design of the Södra Strandgatan intersection

Table 2 : Comparison between existing and new design design

Aspect	Existing Design	Revised Design
Accessibility to Smedijan Parking	The previous design required complex maneuvers, including a left followed by a right turn, to access Smedijan parking. Survey data indicated significant driver frustration and difficulty due to this non-intuitive layout.	The new design streamlines access by enabling a direct approach to Smedijan parking, eliminating multiple turns and reducing navigational confusion. This enhances user convenience and improves the traffic flow around the parking entrance.
Bus Lane Configuration and Priority	Bus lanes were indicated only through road markings, leading to confusion and increased accident risks due to misinterpretations of right-of-way.	The redesign incorporates traffic lights specifically for bus lanes, significantly clarifying priority rules, enhancing safety, and facilitating more effective traffic management.
Egress from Smedijan Parking	Exiting Smedijan parking was problematic with no direct route to Museirondellen, often causing drivers to mistakenly use bus lanes and increasing risks of traffic violations and collisions.	The redesign introduces a clear and direct exit path from Smedijan parking to Museirondellen and the city center, promoting smoother and safer transitions for exiting drivers.
Traffic Light Positioning and Traffic Flow	Traffic lights were placed near the Museirondellen roundabout, causing limited queuing space and frequent congestion, particularly during peak hours.	Traffic lights have been relocated further from the roundabout, in front of the park, which considerably extends the available queuing length and reduces congestion, supporting more organized and efficient traffic flow management.

These enhancements in the redesigned intersection address the operational inefficiencies identified in the old configuration and aim to deliver a safer, more navigable, and less congested driving experience. Each modification has been meticulously planned to augment the overall functionality of the intersection, with a strong emphasis on safety and user convenience.

6.2 Simulation

6.2.1 New Dsign Signal controlling

Figure 31: New design signal control

The revised traffic signal control system shown in Figure 31, largely adheres to the existing operational model designed to optimize traffic flow and prioritize bus movements. This system utilizes a VISVAP chart for managing traffic lights at intersections, focusing on bus detection to adjust signal timings. The configuration for Signal Groups 1 through 5 remains consistent with the previous model, ensuring continuity and familiarity in traffic control. The primary enhancement in the new model is the addition of Signal Group 6, tailored to accommodate changes due to new infrastructure developments.

Signal Group 6, this new signal group is a significant update, introduced to manage traffic efficiently around the newly constructed roundabout. When buses are detected from either the north or the south, the signal at the east side of the new roundabout turns red. This ensures that the flow of traffic around the roundabout remains uninterrupted by bus movements, thus enhancing safety and traffic management in this newly developed area. This addition is specifically designed to address potential traffic issues arising from the roundabout, providing a proactive solution to maintain smooth traffic flow while continuing to prioritize bus transit.This update ensures that, while the core principles of the traffic control system remain intact, the integration of the new Signal Group 6 aligns with urban development and infrastructure changes, enhancing the system's overall effectiveness and responsiveness to evolving traffic patterns.

6.2.2 Density Link Segment

The resulting visualization shown in Figure 32 employs a spectrum of colors to demonstrate the varying levels of traffic density across the interchange's various segments. These segments include critical junctions where vehicles merge into, diverge from, and cross the main traffic streams. The light green color denotes areas with the least traffic, implying that vehicles are likely traveling unimpeded at the designated speed limits. Such low-density zones are desirable in traffic system design as they indicate an efficient and safe utilization of roadways.

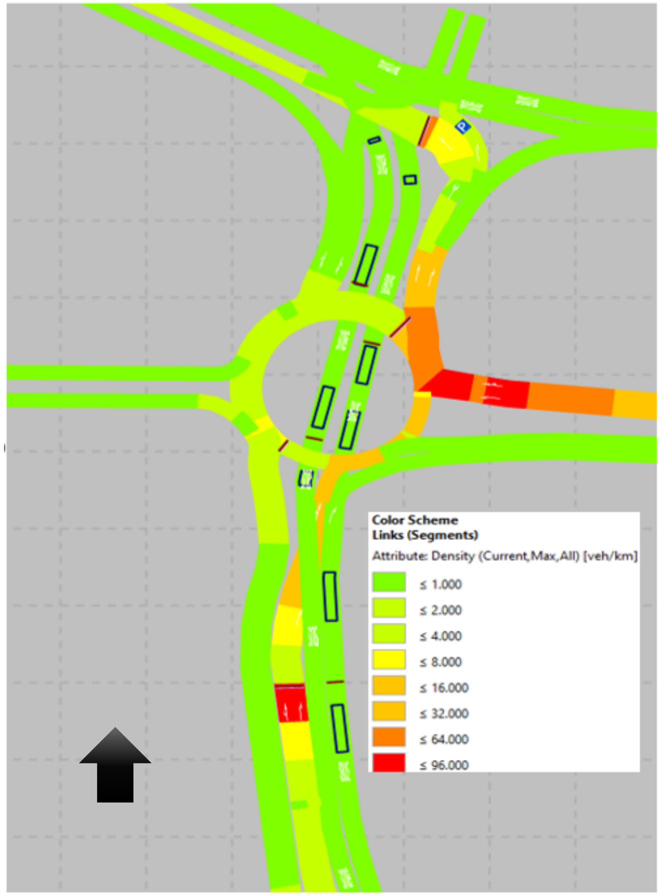

Figure 32: Proposed solution link segment density result

A shift in color from light green, through yellow, to red indicates an increase in traffic density. Yellow suggests a moderate number of vehicles, with traffic likely moving at acceptable speeds, although slower than the light green zones. Red, however, denotes high traffic density where the volume of vehicles surpasses the road's capacity to handle them effectively, resulting in reduced speeds and potential delays. The darkest red zones are particularly troubling as they signal severe congestion, possibly even leading to stop-and-go traffic or complete standstills, Odengatan shows a high density where Ostra strangatan and Södra strangatan show a relatively lower density.

A detailed examination of Figure 32 reveals that the most significant traffic density is typically located at the interchange's convergence and divergence points. Such areas are inherently complex due to the multitude of vehicular movements, including lane changes and speed adjustments, making them prone to congestion. It is precisely these points that typically necessitate thorough analysis and targeted interventions to ameliorate traffic conditions. The insights gained from this simulation are instrumental for traffic analysis professionals. Identifying the root causes and locations of congestion allows for a targeted approach to traffic management. For instance, consistently high density in the northern approach might suggest a substantial inflow of traffic from that direction. Conversely, a lighter density in the southern approach could indicate a lesser volume of incoming vehicles or perhaps a more efficient merging design.

6.2.3 Speed Link Segment

Figure 33 is derived from a traffic simulation model that maps out the average vehicular speeds along various road segments at an intricate junction. The model employs a color-coded scheme to signal traffic speeds, with red indicating slower speeds and dark green suggesting faster movement.

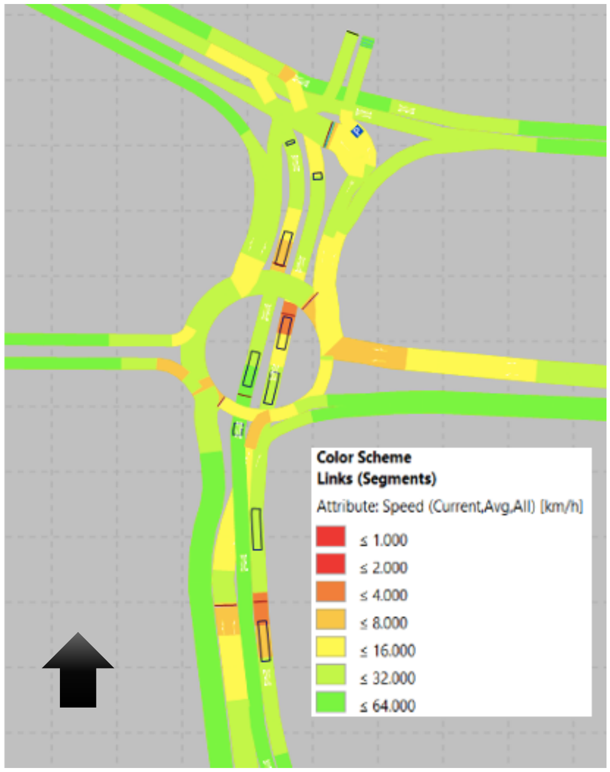

Figure 33: Proposed solution link segment speed result

A detailed analysis reveals that along Östra Strängatan, which traverses the model from south to north, the prevailing colors are green. This indicates that traffic along this route generally moves at higher speeds, which points to less congestion. Conversely, on Odengatan, extending from east to west, there is a prevalence of yellow and orange hues. These colors represent lower speeds, which could be attributed to the road design, traffic volume, or compulsory slowing at intersections. The red areas on the model are particularly neglected, as the new model is enhanced. Between the red and green areas, the gradation of colors suggests a progression where traffic speeds up. These transitional spaces may signal where vehicles are able to accelerate after passing through slower-moving traffic or an intersection.

This simulation is effective in providing a clear and simple visual guide to the flow of traffic within the network. It highlights varying speeds and affords a granular look at how traffic moves through this specific interchange. The accuracy of Östra Strängatan and Odengatan within the simulation is promising, reflecting a realistic portrayal of the traffic conditions. The positive results from the simulation are a crucial step in designing measures to enhance traffic efficiency and safety.

6.2.4 Queuing Link Segment

Figure 34 present the queue length which is considerably lower than critical congestion thresholds typically observed in urban environments, reflect a well-managed traffic system capable of handling the current demand without significant delays.

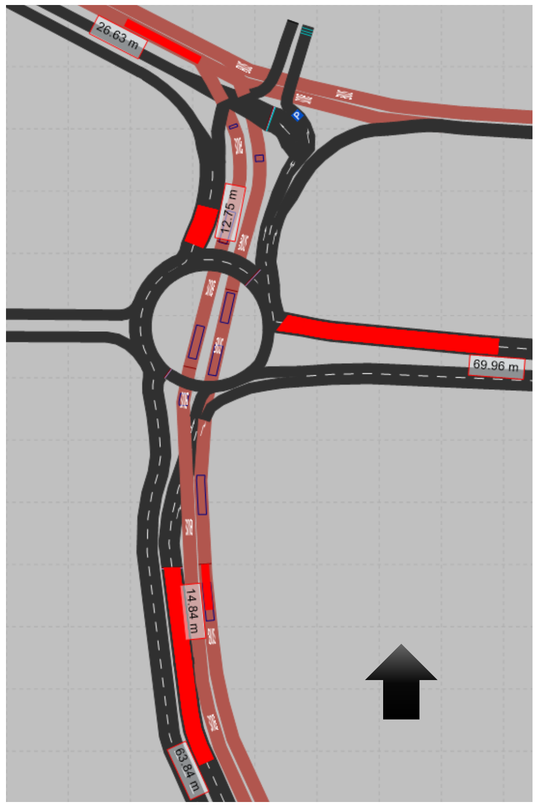

Figure 34: Proposed solution link segment queue length result

The queue length data obtained from the simulation model for Odengatan and Östra Strängatan, with values of 69.96m and 63.84m respectively, indicates a satisfactory level of traffic flow and suggests that the current geometric design of these roads is effectively facilitating vehicle movement. The design elements, such as appropriate lane widths, adequate number of lanes, and efficiently configured intersections, appear to be well-suited to the traffic volumes, thereby minimizing bottlenecks and enhancing overall traffic efficiency. Such positive outcomes not only improve drive times but also contribute to increase safety. These results align with urban traffic management objectives and underscore the success of the existing road configurations at Odengatan and Östra Strängatan.

The traffic simulation has unveiled considerable enhancements across our network, showing marked progress in reducing queues and delays. These improvements are particularly pronounced during peak traffic times, signaling a boost in the effectiveness of our current traffic light setups and overall traffic management strategies. Given these promising results, we are encouraged to explore the node results more closely. This in-depth analysis will grant us a clearer perspective on the distinct roles played by each intersection and junction in the traffic flow, allowing us to pinpoint precise interventions that can further refine the efficiency of our traffic system.

6.2.5 Node Results

6.2.5.1 Östra Strandgatan

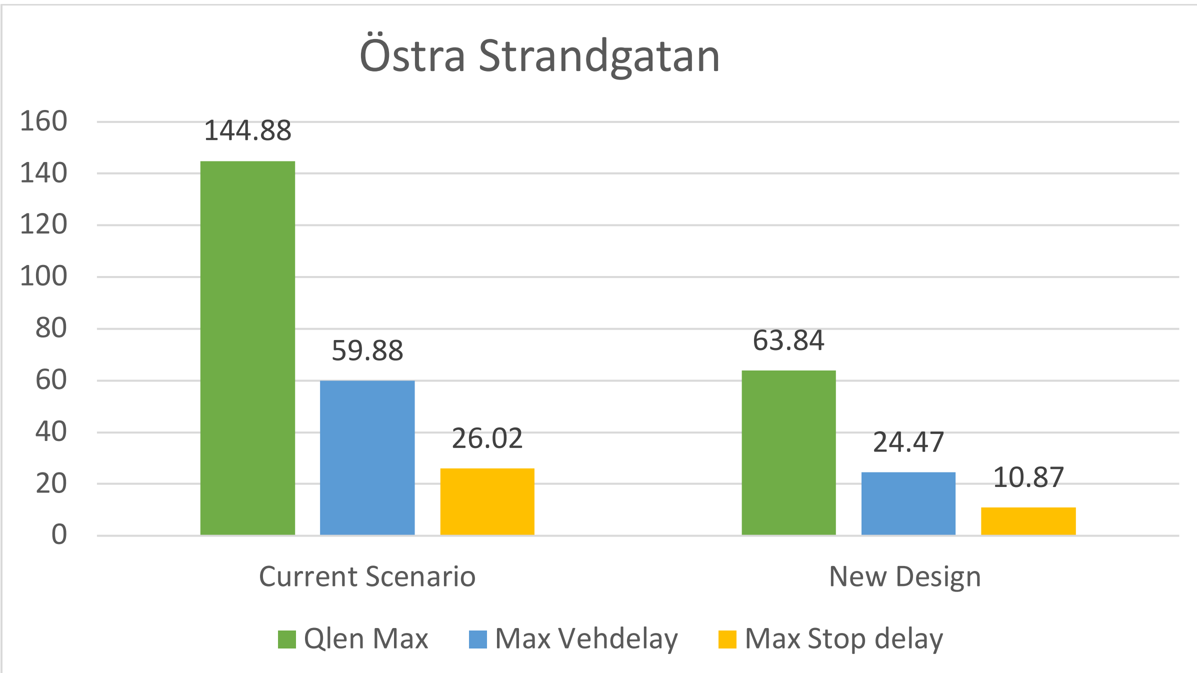

Figure 35: Östra Strandgatan current scenario vs proposed solution scenario

Figure 35 display the maximum queue length (QLENMAX) shows a marked decrease from 144.88 min the current scenario to 63.84 m with the proposed solution of Östra Strandgatan. This substantial drop suggests that the solution effectively reduces the potential for extreme congestion during peak traffic times. When examining delays, we observe that the maximum vehicle delay (Max VEHDELAY) — the longest time a vehicle waits — is cut down from 59.88 seconds to 24.46 seconds with the proposed solution. This implies that, on average, vehicles spend less than half the time waiting compared to the current scenario. The maximum stop delay, which is the longest time vehicles stay immobile, is reduced from 26.02 seconds to 10.86 seconds. This demonstrates that the solution significantly reduces the time vehicles are halted, further alleviating congestion.

6.2.5.2 Odengatan

Figure 36 concerning Odengatan's traffic conditions shows the current challenges with the expected benefits of a newly proposed traffic management strategy.

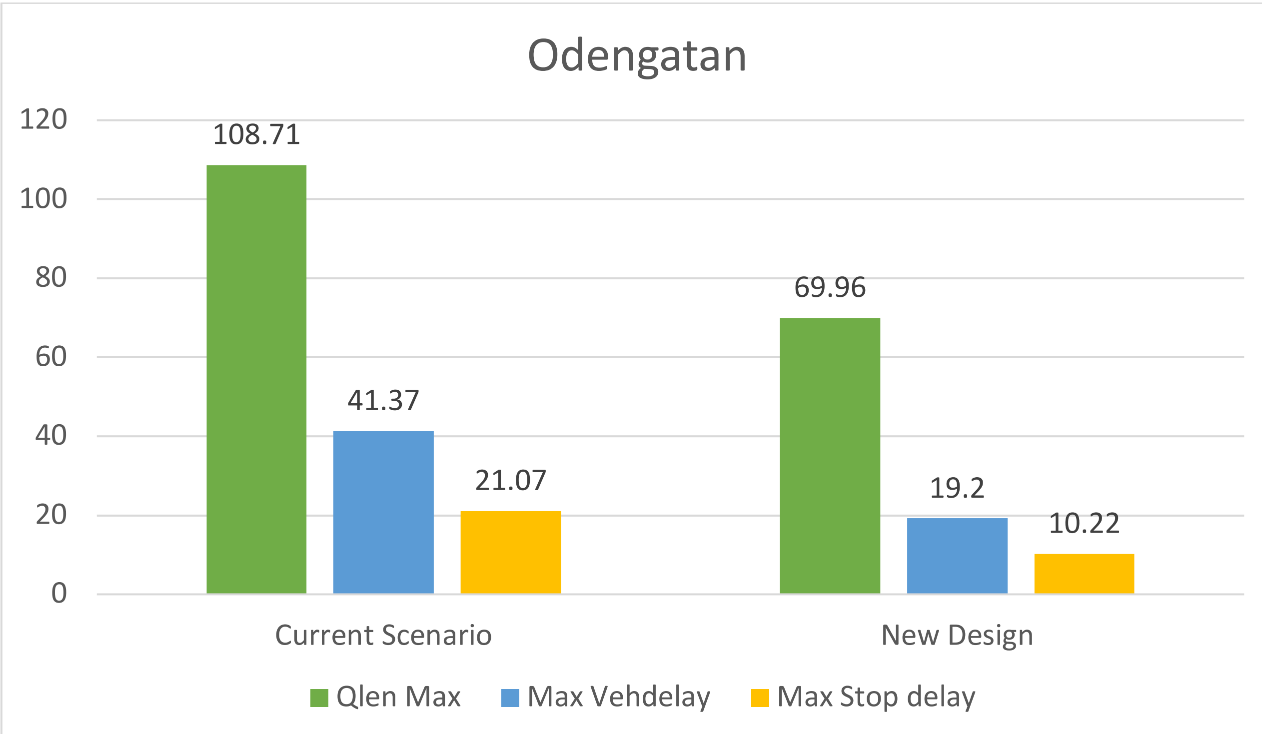

Figure 36: Odengatan current scenario vs proposed solution scenario

For those instances where congestion hits its peak, the maximum queue length is forecasted to shrink from 108.71 to 69.96 m, hinting at the solution's capacity to significantly curb traffic snarls. Furthermore, the longest delay that vehicles currently face would be slashed from 41.37 seconds down to 19.20 seconds, signaling a boost in overall traffic efficiency. Correspondingly, the maximum duration vehicles stay immobile is set to be cut by over half, from 21.07 seconds to a mere 10.22 seconds, underscoring a substantial leap in reducing the idle times at stops and intersections.

6.2.5.3 Södra Strandgatan

Figure 37 represents Södra strangatan, the comparative traffic data showcases the efficiency of a proposed traffic management plan.

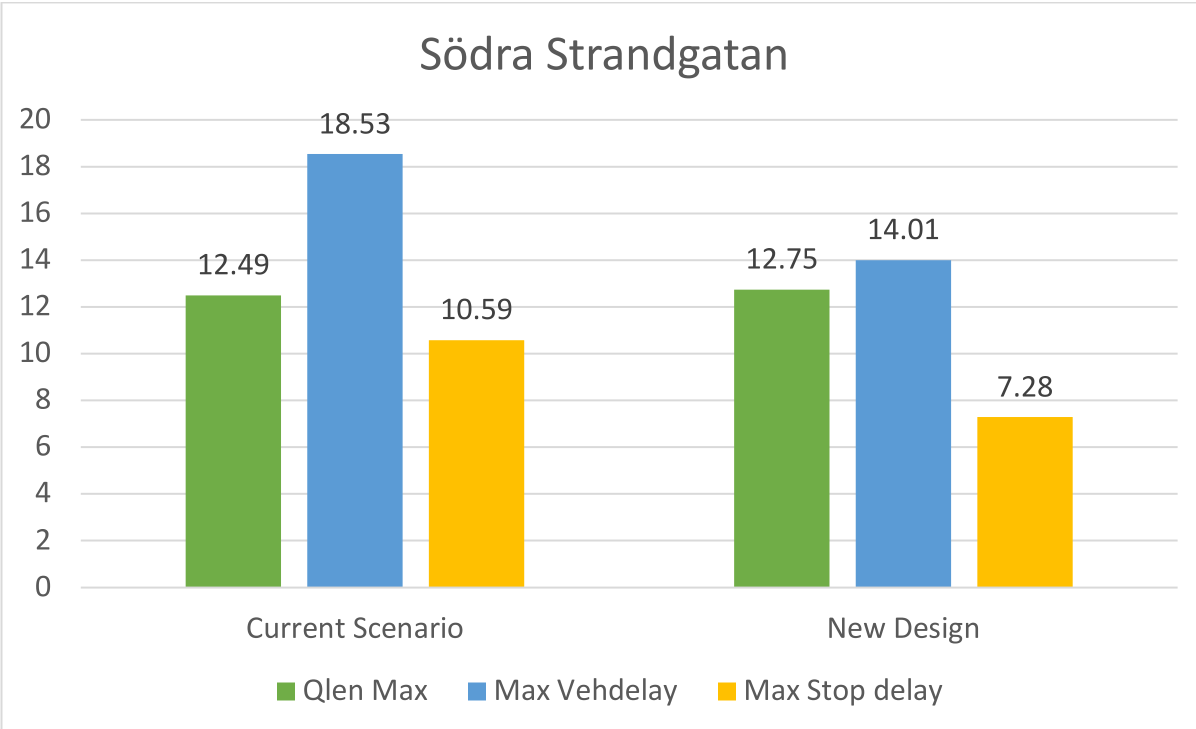

Figure 37: Södra Strandgatan current scenario vs proposed solution scenario

The maximum queue length (QLENMAX) sees a slight increase from 12.49 to 12.75 m, which may point to specific scenarios where congestion is marginally higher than in the current state. In the domain of vehicle delays, the longest wait time (Max VEHDELAY) is anticipated to drop from 18.53 seconds to 14.01 seconds, facilitating a smoother transit experience. The maximum stop delay, marking the lengthiest halt at intersections, is also set to diminish from 10.59 seconds to 7.28 seconds, affirming the proposed solution’s potential to expedite traffic flow and reduce idle times significantly.

6.2.5.4 Comparative Analysis

Table 3: Comparison between current and new design model

Parameter	Current Scenario Details	Proposed Solution Details
Traffic Speed and Flow	- Östra and Södra Strängatan routes predominantly green, indicating higher speeds. - East-west routes show yellow and orange, indicating reduced speeds due to congestion.	- Improved traffic flow throughout, particularly along Östra Strängatan with prevailing green colors indicating less congestion and higher speeds.
Traffic Density	- Colors range from light green to red, with red indicating high density and congestion. - Highest density around areas where vehicles merge and diverge.	- Overall reduction in high-density areas (red), with most areas showing light green and yellow, suggesting lower congestion levels.
Queue Length	- East Road (Odengatan): 108.71m - South Road (Östra Strängatan): 144.88m - Average queue length in key areas contributes to congestion.	- Odengatan: Reduced to 69.96m - Östra Strängatan: Reduced to 63.84m - General reduction in queue lengths suggests improved traffic flow.
Vehicle Delays	- Max Vehicle Delay (Max VEHDELAY): 59.88 seconds at peak - Delays signify inefficiency during high traffic periods.	- Max Vehicle Delay (Max VEHDELAY): Reduced to 24.46 seconds - Reduction in waiting times, enhancing efficiency during peak periods.
Stop Delays	- Max Stop Delay: 26.31 seconds - Long stop delays indicative of traffic signal issues and congestion at intersections.	- Max Stop Delay: Reduced to 10.86 seconds - Significant decrease in idle times at stops, reflecting better signal timing and flow management.
Traffic Management	- Suboptimal signal timings and traffic light configurations contributing to extensive queuing and delays.	- Enhanced traffic light setups and improved traffic management strategies lead to fewer queues and delays, especially during peak traffic times.

The analysis in Table has clearly demonstrated that the proposed solutions offer substantial improvements over the current system, enhancing traffic flow, reducing congestion, and minimizing vehicle wait times across the network. By effectively addressing key issues such as high traffic density and lengthy queue times at critical junctions, the proposed changes promise to streamline traffic operations. This analysis supports the implementation of the proposed traffic management strategies as they are poised to significantly enhance the efficiency and sustainability of the road system.

7 Discussion

7.1 Discussion of results

The traffic simulations provided valuable insights into how different traffic management strategies affect the flow and efficiency of the network. Speed variability across various segments demonstrated a clear impact of bus prioritization on traffic speeds, where segments with bus prioritization showed reduced speeds due to the additional space and time allocated to buses. Additionally, the simulations showed increased congestion at intersections with complex designs and bus prioritization, particularly during peak traffic hours. This congestion indicates an imbalance in traffic management, where the needs of buses overshadow the smooth flow of other vehicles. The extended queue lengths observed in the simulations are a direct result of these prioritization measures and intersection designs, contributing to increased vehicle idling times.

The observed variations in traffic speed and notable congestion at certain intersections and road segments revealed by our traffic simulation analysis can largely be attributed to bus prioritization strategies, such as those implemented in Museirondellen with throughabouts—roundabouts that incorporate dedicated bus lanes. While these strategies are designed to enhance public transport efficiency, they can inadvertently impact the overall flow of general traffic by reducing the available road space for non-bus vehicles and causing delays, particularly at complex intersections.

The effects of bus prioritization at Museirondellen are particularly pronounced, as they directly influence the dynamics of both bus and general vehicle traffic. This area, where dedicated lanes for buses cut through the roundabout, tends to exacerbate congestion during peak times when traffic volumes are highest. This results in longer queues and increased waiting times at signals, where traffic controls are heavily skewed in favor of buses.

Moreover, the intricate intersection design at Södra Strandgatan further complicates traffic flow. This complex design not only challenges drivers' navigational abilities but also contributes to congestion by hindering the smooth movement of vehicles through the intersection. The combined impact of these design features and prioritization strategies calls for a nuanced approach to traffic management that carefully balances the needs of public transport and general traffic. To alleviate these challenges, it is crucial to employ advanced traffic management systems that dynamically adjust to real-time traffic conditions and more evenly distribute the priority given at signals between buses and general traffic. Enhancing the physical design of intersections, like those at Södra Strandgatan, and optimizing the configuration of bus lanes at Museirondellen could also help ensure smoother traffic flow for all vehicles.

Discussion

Survey results indicate a crucial need for the redesign of Södra Strandgatan to address safety concerns, confusion, and navigational difficulties. The proposed redesign should focus on creating a clearer and more intuitive layout, enhancing road safety through improved markings and signage, and simplifying intersections to reduce cognitive load for drivers. By making these changes, the redesign will not only improve immediate driving conditions but also foster long-term confidence and well-being for regular users of the road. This approach aims to transform Södra Strandgatan into a safer, more efficient, and user-friendly roadway.

Bus prioritization at Museirondellen and the complex intersection designs at Södra Strandgatan are crucial for supporting efficient public transport, it is essential to manage their impact on general traffic effectively. Adopting a more integrated and flexible approach to traffic management, which involves not only technical adjustments but also a focus on improving communication among all road users, can enhance the overall efficiency of the traffic network, reduce congestion, and improve safety and satisfaction for all road users.

7.2 Discussion of new design

A comprehensive redesign of the Södra Strandgatan intersection is proposed by us in this master thesis, underpinned by the goals of enhancing traffic efficiency, safety, and driver experience. This initiative aligns with the standards set forth in Trafikverket VGU 2022, employing a robust simulation analysis that encompasses evaluations of speed, queue length, density, and node-specific results to compare the proposed design against the existing structure.

The traffic simulations provide pivotal data, evidencing the practical benefits attributed to the redesigned intersection. A notable shift is observed in traffic density, with a reduction in high congestion zones (red) transitioning to lower congestion levels (yellow and green zones), indicating a more efficient movement of traffic. The analysis of speeds along critical corridors such as Östra Strängatan shows an enhancement from slower speeds (marked in orange and red) to faster speeds (green), suggesting an alleviation of congestion.

Furthermore, the redesign leads to significant reductions in queue lengths across various points of the intersection, especially notable at Odengatan and Östra Strängatan. The maximum queue lengths and vehicle delays are substantially reduced, indicating that the intersection is better equipped to manage peak traffic volumes efficiently, which aligns with the objectives of urban traffic management.

The results derived from node analysis reinforce the efficacy of the new design in managing traffic flows effectively. The average and maximum queue lengths demonstrate considerable reductions, indicative of smoother transitions at intersections and a decreased likelihood of congestion. Additionally, there is a noticeable decrease in vehicle delays, affirming that the new configurations of traffic signals and lane arrangements are instrumental in minimizing wait times.

The new design offers several improvements over the current configuration, primarily aiming to create a more user-friendly driving experience, effectively reducing driver stress and confusion. By simplifying traffic flows and enhancing the clarity of lane demarcations and traffic signals, the redesign focuses on improving navigational ease and reducing the potential for accidents. This adjustment not only promotes safety but also enhances the overall clarity of the intersection. Traffic efficiency is further optimized through the strategic positioning of traffic lights and improved lane usage, which helps in mitigating queuing times, particularly during peak traffic hours. Additionally, the integration of intuitive design elements such as color-coded hatching and innovative features like the drop refuge plays a crucial role in making the intersection more accessible and less intimidating for drivers, thus contributing to a safer and more efficient traffic system.

7.3 Limitations and challenges

In examining the limitations and challenges presented in the thesis on urban traffic management at the Museirondellen and Södra Strandgatan intersections in Jönköping, several key issues emerge.The data availability and accuracy concerns highlight a fundamental challenge. The thesis relies on traffic data that may not completely capture the variability of real-world conditions such as fluctuations during different times of the day or seasonal variations, which can significantly impact the accuracy of traffic simulations and the efficacy of proposed management strategies.In addtion , while the use of simulation models like PTV Vissim is instrumental in analyzing traffic dynamics, these models have inherent constraints. They often require simplifications that may not fully reflect complex interactions in urban traffic systems, especially with non-motorized traffic participants like pedestrians and cyclists. This limitation can affect the reliability of the results and the feasibility of the suggested improvements. The generalizability of the study's findings also poses a significant limitation. The traffic management solutions tailored for the specific conditions of Jönköping's intersections may not be directly applicable to other urban areas with different traffic compositions, behaviors, and infrastructural layouts. This limitation restricts the broader applicability of the thesis outcomes, necessitating additional research and modifications to adapt these solutions to different urban contexts.

Moreover, the implementation of new traffic management strategies is subject to the acceptance by local communities and stakeholders. Any resistance from these groups can pose substantial challenges to the deployment of new systems, despite their technical soundness. Effective stakeholder engagement and public relations strategies are essential to mitigate such resistance and foster community support for transformative traffic solutions. Lastly, a notable academic hurdle faced during the study was the scarcity of specific literature related to similar complex intersection. This lack of targeted research made it difficult to draw parallels with similar case studies or to benchmark the solutions against established practices. The absence of directly relevant studies necessitated a reliance on more general or indirectly related literature, which may not provide the most precise guidance for addressing the unique challenges of the studied intersections.

These limitations and challenges underscore the need for a comprehensive approach in urban traffic management research that incorporates robust data collection, adaptable simulation methodologies, extensive stakeholder engagement, and continuous academic inquiry to enhance the relevance and applicability of traffic solutions in various urban settings.

7.4 Future research

An essential avenue for future research arising from the thesis on traffic management at the Museirondellen and Södra Strandgatan intersections in Jönköping centers on the profound impact that parking facilities, particularly the Smedjan Parking House, have on local traffic patterns. This parking facility, due to its central location and design, significantly contributes to the complex and confusing traffic geometries observed in the area. It's crucial for future studies to conduct a detailed evaluation of the actual need for parking in this densely trafficked area. Researchers should assess whether the current parking supply aligns with demand and consider the potential benefits of modifying, reducing, or relocating the Smedjan Parking House. Such changes could potentially reduce congestion, simplify traffic flows, and enhance overall safety and efficiency within the urban environment.

Expanding on this, further research should also delve into the integration of non-motorized traffic participants within the urban traffic management framework. This involves a nuanced study of how various traffic management strategies and intersection designs influence the safety and mobility of pedestrians and cyclists. It's important to develop and test models that more accurately predict and accommodate the interactions between motorized and non-motorized traffic, aiming to create a safer, more inclusive urban traffic environment. Moreover, the emergence of autonomous vehicles presents another critical research frontier. The increasing prevalence of autonomous vehicles necessitates a reassessment of traditional traffic management practices at complex urban intersections. Future research should explore the implications of autonomous vehicles on traffic dynamics, focusing on necessary adjustments in road infrastructure, signalization, and traffic regulations. This would ensure that these technological advancements are seamlessly integrated into the urban landscape, facilitating coexistence with traditional vehicles and enhancing the overall efficiency of traffic systems.

These proposed areas of research would not only build upon the findings of the current thesis but also help urban planners and traffic engineers anticipate and adapt to evolving challenges in vehicle technology and urban mobility trends. By addressing these key issues, future research can contribute significantly to the development of more adaptive, resilient, and efficient urban traffic management strategies.

8 Conclusion

In conclusion, this master thesis has elucidated the significant impacts of bus prioritization strategies on traffic dynamics, particularly at critical intersections such as Museirondellen and Södra Strandgatan. The simulations conducted have provided a robust foundation for understanding the dualistic nature of these strategies—while they enhance public transport efficiency, they also disrupt the fluidity of general traffic. This research underscores the necessity for a balanced traffic management approach that accommodates both public and private transport needs effectively.

The proposed redesign of Södra Strandgatan, as detailed in this thesis, presents a strategic response to the challenges identified. By enhancing road layout clarity and simplifying navigation, the redesign aims to alleviate congestion, minimize vehicle idling times, and improve overall traffic safety. These improvements are pivotal in fostering a more conducive driving environment, thus enhancing user experience and satisfaction. Furthermore, the findings advocate for the adoption of advanced, dynamic traffic management systems capable of adjusting in real time to traffic conditions. Such systems are crucial for ensuring equitable signal prioritization, thereby facilitating smoother traffic flow and reducing delays.

This thesis contributes to the broader discourse on urban traffic management by demonstrating the importance of integrating the needs of diverse traffic types within a unified management framework. It calls for ongoing evaluations and adaptable strategies that respond to the evolving demands of urban environments. The implementation of the recommended changes is expected to lead to significant enhancements in traffic efficiency and urban livability, aligning with contemporary goals of sustainable urban development. This research not only highlights the challenges posed by current traffic management strategies but also provides practical solutions aimed at creating a more balanced and efficient urban traffic system.

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Appendix A

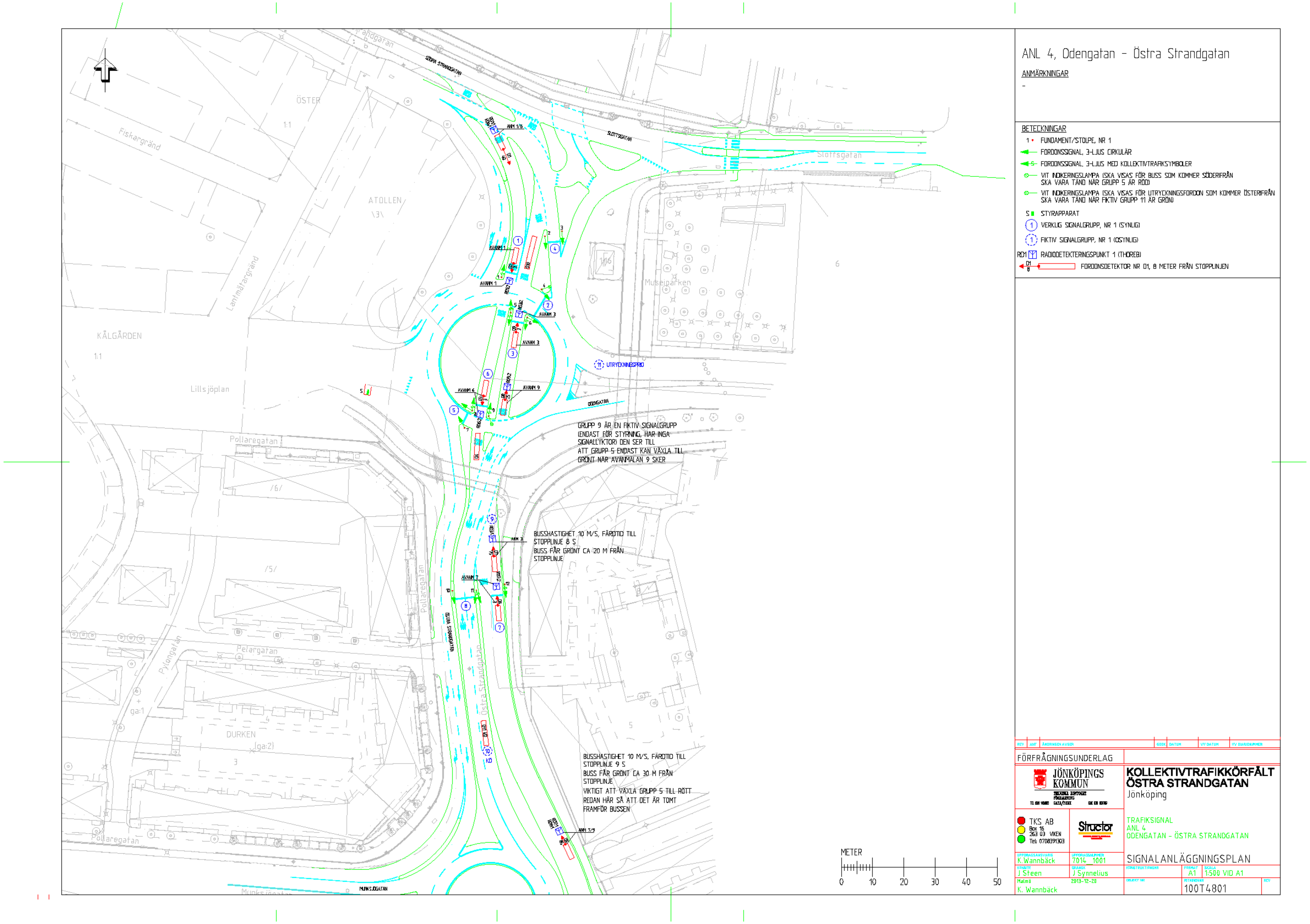

Figure 38: Plan drawing for existing detector data

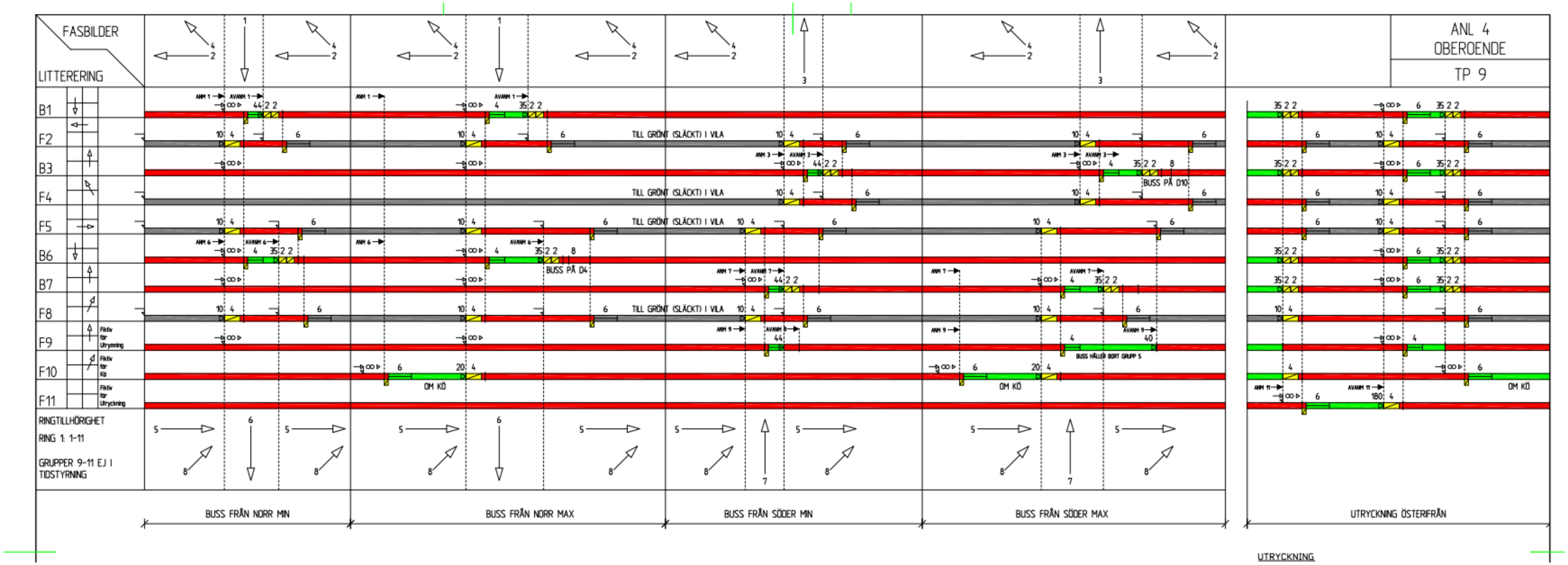

Figure 39: Existing signal timing

Appendix B

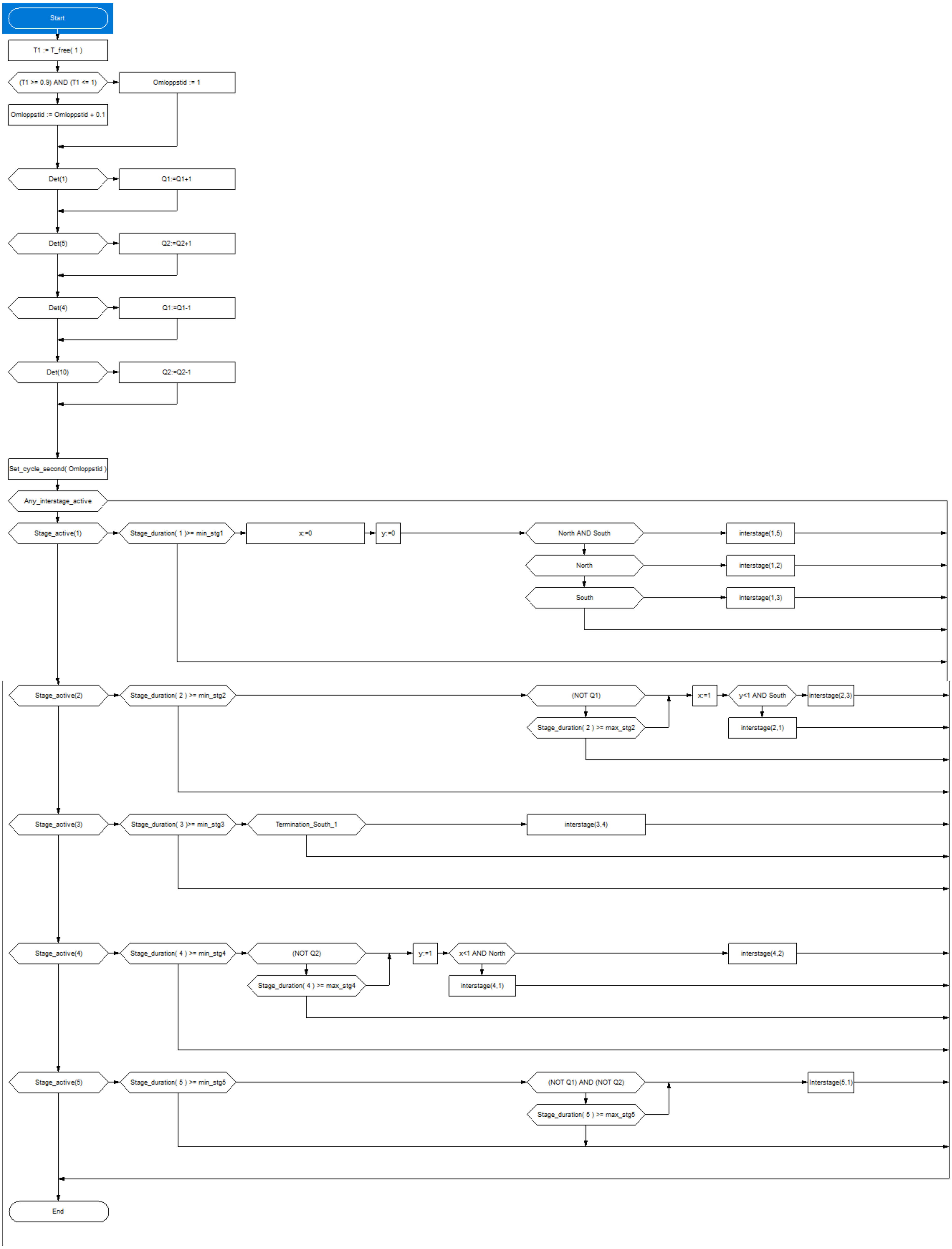

Figure 40: The complete VISVAP chart

Appendix C

Table 3: Current node results

MOVEMENT	QLEN	QLENMAX	VEHS(ALL)	LOS(ALL)	LOSVAL(ALL)	VEHDELAY(ALL)	STOPDELAY(ALL)	STOPS(ALL)
1-3: östra strangatan@322.7-8: östra strangatan@163.3	22,98	144,88	70	LOS_E	5	55,94	24,71	3,49
1-3: östra strangatan@322.7-9: Odengatan@85.9	22,98	144,88	87	LOS_A	1	9,38	6,53	0,39
1-3: östra strangatan@322.7-11: Södra strangatan@202.7	22,98	144,88	78	LOS_D	4	48,55	19,55	3,09
1-3: östra strangatan@322.7-17: Slottsgatan@31.1	22,98	144,88	71	LOS_E	5	59,88	26,02	3,77
1-4: Odengatan@606.7-8: östra strangatan@163.3	31,3	108,71	123	LOS_C	3	30,65	14,48	1,76
1-4: Odengatan@606.7-9: Odengatan@85.9	31,3	108,71	122	LOS_D	4	41,37	21,07	2,48
1-4: Odengatan@606.7-11: Södra strangatan@202.7	31,3	108,71	128	LOS_C	3	26,68	9,94	1,91
1-4: Odengatan@606.7-17: Slottsgatan@31.1	31,3	108,71	119	LOS_D	4	40,33	15,75	2,58
1-10: Södra strangatan@300.3-8: östra strangatan@163.3	0,39	12,49	39	LOS_A	1	3,76	0,74	0,38
1-10: Södra strangatan@300.3-9: Odengatan@85.9	0,39	12,49	40	LOS_B	2	10,15	5,3	0,72
1-10: Södra strangatan@300.3-11: Södra strangatan@202.7	0,39	12,49	48	LOS_B	2	18,53	10,59	1,06
1-10: Södra strangatan@300.3-17: Slottsgatan@31.1	0,39	12,49	46	LOS_B	2	16,95	8,43	0,87
1-15: Bus Lane@318.9-18: Bus Lane@864.3	0,57	14,99	16	LOS_C	3	33,47	9,2	1,69
1-18: Bus Lane@613.4-18: Bus Lane@864.3	0	0	37	LOS_A	1	0,14	0	0
1-19: Bus Lane@325.3-16: Bus Lane@256.3	1,2	43,8	34	LOS_B	2	19,31	8,78	0,65
1-19: Bus Lane@325.3-17: Slottsgatan@31.1	0	0	0	LOS_A				
1	8,06	144,88	1058	LOS_C	3	31,4	13,94	1,93

Table 4: scenario 1 node results

MOVEMENT	QLEN	QLENMAX	VEHS(ALL)	LOS(ALL)	LOSVAL(ALL)	VEHDELAY(ALL)	STOPDELAY(ALL)	STOPS(ALL)
1-3: östra strangatan@322.7-8: östra strangatan@163.3	24,3	155,72	75	LOS_E	5	60,19	26,31	3,75
1-3: östra strangatan@322.7-9: Odengatan@85.9	24,3	155,72	98	LOS_B	2	10,45	7,62	0,35
1-3: östra strangatan@322.7-11: Södra strangatan@202.7	24,3	155,72	84	LOS_D	4	50,09	20,41	2,95
1-3: östra strangatan@322.7-17: Slottsgatan@31.1	24,3	155,72	77	LOS_D	4	52,8	22,07	3,35
1-4: Odengatan@606.7-8: östra strangatan@163.3	47,8	150,15	131	LOS_D	4	50,15	23,15	3,05
1-4: Odengatan@606.7-9: Odengatan@85.9	47,8	150,15	126	LOS_E	5	55,59	23,47	3,45
1-4: Odengatan@606.7-11: Södra strangatan@202.7	47,8	150,15	140	LOS_D	4	46,77	16,37	3,18
1-4: Odengatan@606.7-17: Slottsgatan@31.1	47,8	150,15	124	LOS_E	5	59,79	25,32	3,19
1-10: Södra strangatan@300.3-8: östra strangatan@163.3	0,52	13,01	39	LOS_A	1	7,14	3,21	0,59
1-10: Södra strangatan@300.3-9: Odengatan@85.9	0,52	13,01	40	LOS_B	2	11,38	6,36	0,68
1-10: Södra strangatan@300.3-11: Södra strangatan@202.7	0,52	13,01	48	LOS_C	3	21,33	11,94	1,23
1-10: Södra strangatan@300.3-17: Slottsgatan@31.1	0,52	13,01	46	LOS_C	3	21,26	11,61	1,15
1-15: Bus Lane@318.9-18: Bus Lane@864.3	0,51	14,64	17	LOS_C	3	29,78	7,9	1,18
1-18: Bus Lane@613.4-18: Bus Lane@864.3	0	0	37	LOS_A	1	0,21	0	0
1-19: Bus Lane@325.3-16: Bus Lane@256.3	1,11	43,61	34	LOS_B	2	13,11	5,02	0,38
1-19: Bus Lane@325.3-17: Slottsgatan@31.1	0	0	0	LOS_A				
1	10,61	155,72	1116	LOS_D	4	40,36	17,34	2,41

Table 5: scenario 2 node results

MOVEMENT	QLEN	QLENMAX	VEHS(ALL)	LOS(ALL)	LOSVAL(ALL)	VEHDELAY(ALL)	STOPDELAY(ALL)	STOPS(ALL)
1-3: östra strangatan@322.7-8: östra strangatan@163.3	26,15	198,86	82	LOS_E	5	61,6	27,95	4,12
1-3: östra strangatan@322.7-9: Odengatan@85.9	26,15	198,86	106	LOS_B	2	8,21	9,36	0,37
1-3: östra strangatan@322.7-11: Södra strangatan@202.7	26,15	198,86	86	LOS_D	4	53,69	23,76	3,07
1-3: östra strangatan@322.7-17: Slottsgatan@31.1	26,15	198,86	86	LOS_D	4	54,74	23,62	3,86
1-4: Odengatan@606.7-8: östra strangatan@163.3	99,29	239,63	137	LOS_E	5	77,01	25,32	5,66
1-4: Odengatan@606.7-9: Odengatan@85.9	99,29	239,63	131	LOS_F	6	89,2	32,64	6,73
1-4: Odengatan@606.7-11: Södra strangatan@202.7	99,29	239,63	145	LOS_F	6	92,2	31,39	7,05
1-4: Odengatan@606.7-17: Slottsgatan@31.1	99,29	239,63	131	LOS_F	6	109,09	39,51	7,86
1-10: Södra strangatan@300.3-8: östra strangatan@163.3	0,54	13,6	39	LOS_A	1	8,99	4,1	0,56
1-10: Södra strangatan@300.3-9: Odengatan@85.9	0,54	13,6	40	LOS_B	2	19,17	7,5	0,82
1-10: Södra strangatan@300.3-11: Södra strangatan@202.7	0,54	13,6	48	LOS_B	2	21,91	11,8	1,06
1-10: Södra strangatan@300.3-17: Slottsgatan@31.1	0,54	13,6	46	LOS_B	2	23,11	12,4	1,11
1-15: Bus Lane@318.9-18: Bus Lane@864.3	0,32	14,66	17	LOS_C	3	26,04	5,07	1,18
1-18: Bus Lane@613.4-18: Bus Lane@864.3	0	0	37	LOS_A	1	0,2	0	0
1-19: Bus Lane@325.3-16: Bus Lane@256.3	2,1	48,83	34	LOS_B	2	15,58	7,73	0,79
1-19: Bus Lane@325.3-17: Slottsgatan@31.1	0	0	0	LOS_A				
1	18,13	239,63	1165	LOS_E	5	58,65	21,38	4,18

Table 6: scenario 3 node results

MOVEMENT	QLEN	QLENMAX	VEHS(ALL)	LOS(ALL)	LOSVAL(ALL)	VEHDELAY(ALL)	STOPDELAY(ALL)	STOPS(ALL)
1-3: östra strangatan@322.7-8: östra strangatan@163.3	98,6	239,05	81	LOS_F	6	124,25	59	7,25
1-3: östra strangatan@322.7-9: Odengatan@85.9	98,6	239,05	113	LOS_B	2	14,57	9,4	0,58
1-3: östra strangatan@322.7-11: Södra strangatan@202.7	98,6	239,05	86	LOS_F	6	124,35	60,46	7,14
1-3: östra strangatan@322.7-17: Slottsgatan@31.1	98,6	239,05	86	LOS_F	6	117,67	49,16	7,3
1-4: Odengatan@606.7-8: östra strangatan@163.3	155,35	309,02	138	LOS_F	6	133,91	49,29	9,62
1-4: Odengatan@606.7-9: Odengatan@85.9	155,35	309,02	132	LOS_F	6	146,62	57,84	10,58
1-4: Odengatan@606.7-11: Södra strangatan@202.7	155,35	309,02	147	LOS_F	6	146,92	54,97	10,8
1-4: Odengatan@606.7-17: Slottsgatan@31.1	155,35	309,02	134	LOS_F	6	142,77	53,99	10
1-10: Södra strangatan@300.3-8: östra strangatan@163.3	0,57	14,68	39	LOS_A	1	11,3	5,1	0,44
1-10: Södra strangatan@300.3-9: Odengatan@85.9	0,57	14,68	40	LOS_B	2	16,79	7,9	0,8
1-10: Södra strangatan@300.3-11: Södra strangatan@202.7	0,57	14,68	48	LOS_B	2	25,13	12,8	0,9
1-10: Södra strangatan@300.3-17: Slottsgatan@31.1	0,57	14,68	46	LOS_B	2	20,16	13,1	1,07
1-15: Bus Lane@318.9-18: Bus Lane@864.3	0,36	14,93	19	LOS_C	3	26,85	5,06	1,21
1-18: Bus Lane@613.4-18: Bus Lane@864.3	0	0	37	LOS_A	1	0,16	0	0
1-19: Bus Lane@325.3-16: Bus Lane@256.3	0,81	42,83	34	LOS_B	2	10,91	3,02	0,32
1-19: Bus Lane@325.3-17: Slottsgatan@31.1	0	0	0	LOS_A				
1	36,52	309,02	1180	LOS_F	6	96,92	39,32	6,54

Table 7: Solution node results

MOVEMENT	QLEN	QLENMAX	VEHS(ALL)	LOS(ALL)	LOSVAL(ALL)	VEHDELAY(ALL)	STOPDELAY(ALL)	STOPS(ALL)
1 - 3: östra strangatan@61.7 - 8: östra strangatan@425.1	5,792059	63,84009	83	LOS_C	3	24,46855	10,866567	1,060241
1 - 3: östra strangatan@61.7 - 9: Odengatan@664.0	5,792059	63,84009	77	LOS_B	2	10,83872	7,355566	0,38961
1 - 3: östra strangatan@61.7 - 17: Slottsgatan@608.6	5,792059	63,84009	82	LOS_B	2	19,447495	9,028518	0,707317
1 - 3: östra strangatan@61.7 - 24: Södra strangatan@414.6	5,792059	63,84009	173	LOS_B	2	19,515032	7,713947	0,728324
1 - 4: Odengatan@30.8 - 8: östra strangatan@425.1	2,740097	69,957686	102	LOS_A	1	6,014219	2,902232	0,382353
1 - 4: Odengatan@30.8 - 9: Odengatan@664.0	2,740097	69,957686	88	LOS_B	2	19,203611	10,216866	1,045455
1 - 4: Odengatan@30.8 - 17: Slottsgatan@608.6	2,740097	69,957686	114	LOS_A	1	3,159909	0,991486	0,175439
1 - 4: Odengatan@30.8 - 24: Södra strangatan@414.6	2,740097	69,957686	220	LOS_B	2	11,635442	5,382543	0,6
1 - 10: Södra strangatan@47.0 - 8: östra strangatan@425.1	0,065285	12,75341	39	LOS_A	1	0,898928	0	0
1 - 10: Södra strangatan@47.0 - 9: Odengatan@664.0	0,065285	12,75341	31	LOS_B	2	11,023439	6,634009	0,645161
1 - 10: Södra strangatan@47.0 - 17: Slottsgatan@608.6	0,065285	12,75341	31	LOS_B	2	10,011164	4,910814	0,419355
1 - 10: Södra strangatan@47.0 - 24: Södra strangatan@414.6	0,065285	12,75341	27	LOS_B	2	14,008387	7,276587	0,740741
1 - 15: Bus Lane@58.9 - 18: Bus Lane@1152.8	0,463547	14,837719	16	LOS_C	3	30,588195	7,860897	1,25
1 - 18: Bus Lane@35.9 - 18: Bus Lane@1152.8	0	0	37	LOS_A	1	0,198065	0	0
1 - 19: Bus Lane@47.0 - 16: Bus Lane@521.1	0,080759	26,629484	34	LOS_B	2	13,628874	3,850094	0,411765
1 - 19: Bus Lane@47.0 - 17: Slottsgatan@608.6	0,080759	26,629484	0	LOS_A				
1	1,523625	69,957686	1154	LOS_B	2	13,072045	5,932834	0,582322

Appendix D

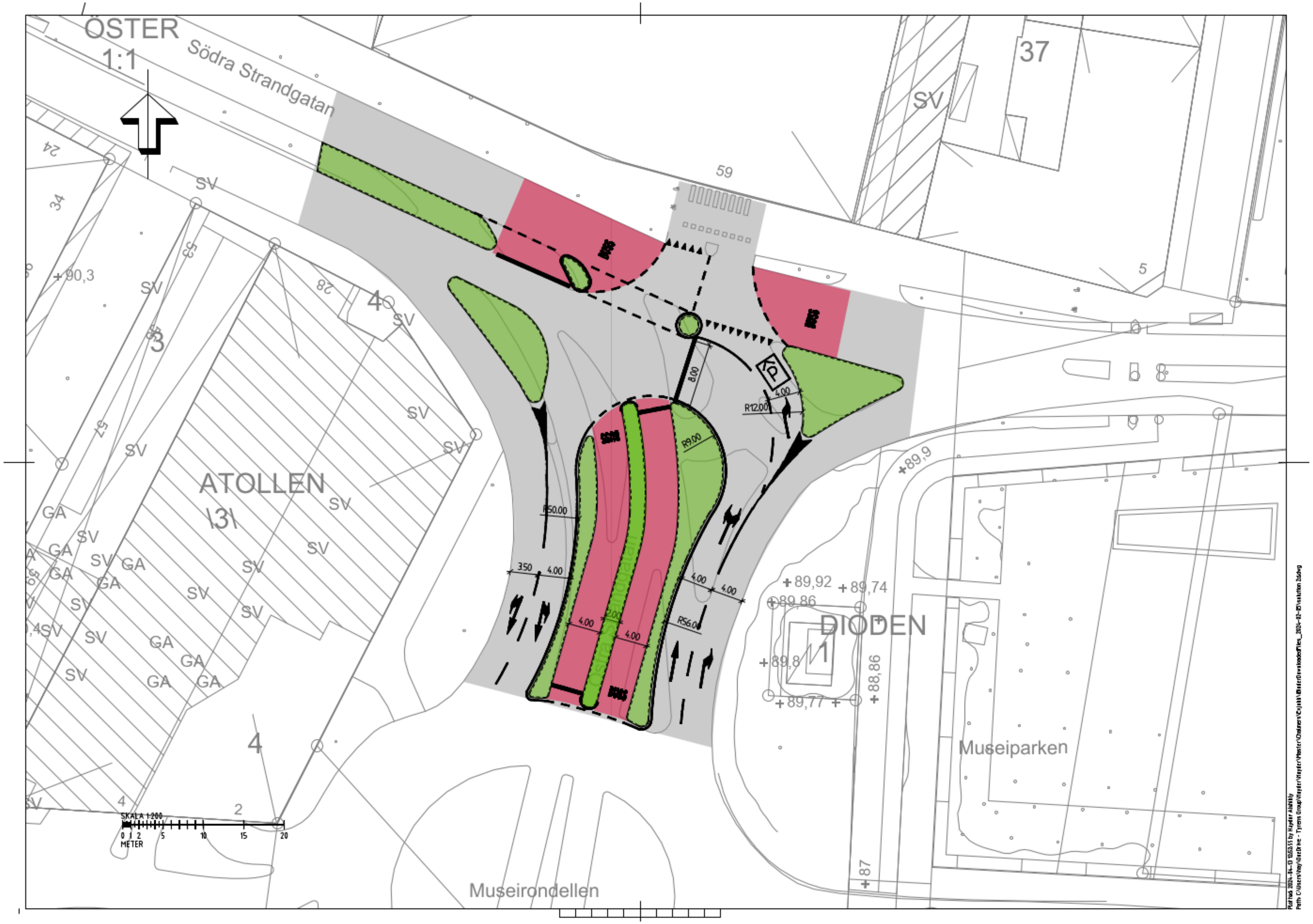

Figure 41: New design plan drawing